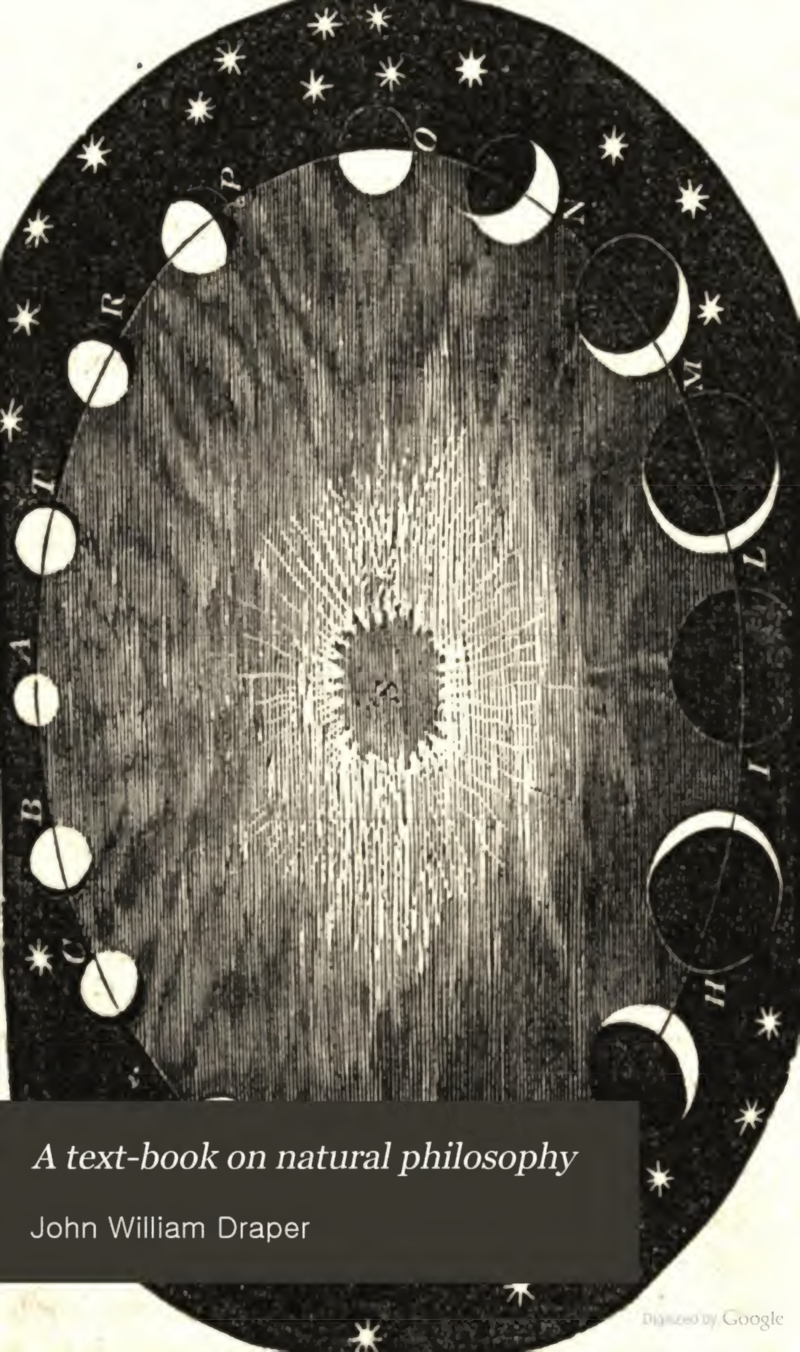

A text-book on natural philosophy

John William Draper

BY THE SAME AUTHOR,

A Text-book on Chemistry,

FOR THE USE OF SCHOOLS AND COLLEGES.

11-79

A

TEXT-BOOK

ON

NATURAL PHILOSOPHY.

FOR THE USE OF

SCHOOLS AND COLLEGES.

CONTAINING THE MOST RECENT DISCOVERIES AND FACTS COMPILED FROM THE BEST AUTHORITIES.

BY

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PREFACE.

THE success which has attended the publication of my "Text-Book on Chemistry," four large editions of it having been called for in less than a year, has induced me to publish, in a similar manner, the Lectures I formerly gave on Natural Philosophy when professor of that science.

It will be perceived that I have made what may appear an innovation in the arrangement of the subject; and, instead of commencing in the usual manner with Mechanics, the Laws of Motion, &c., I have taught the physical properties of Air and Water first. This plan was followed by many of the most eminent writers of the last century; and it is my opinion, after an extensive experience in public teaching, that it is far better than the method ordinarily pursued.

The main object of a teacher should be to communicate a clear and general view of the great features of his science, and to do this in an agreeable and short manner. It is too often forgotten that the beginner knows nothing; and the first thing to be done is to awaken in him an interest in the study, and to present to him a view of the scientific relations of those natural objects with which he is most familiar. When his curiosity is aroused, he will readily go through things that are abstract and forbidding;

which, had they been presented at first, would have discouraged or perhaps disgusted him.

I am persuaded that the superficial knowledge of the physical sciences which so extensively prevails is, in the main, due to the course commonly pursued by teachers. The theory of Forces and of Equilibrium, the laws and phenomena of Motion, are not things likely to allure a beginner; but there is no one so dull as to fail being interested with the wonderful effects of the weight, the pressure, or the elasticity of the air. It may be more consistent with a rigorous course to present the sterner features of science first; but the object of instruction is more certainly attained by offering the agreeable.

But though this work is essentially a text-book upon my Lectures, I have incorporated in it, from the most recent authors, whatever improvements have of late been introduced in the different branches of Natural Philosophy, either as respects new methods of presenting facts or the arrangement of new discoveries. In this sense, this work is to be regarded as a compilation from the best authorities adapted to the uses of schools and colleges.

Disclaiming, therefore, any pretensions to originality, except where directly specified in the body of the work, I ought more particularly to refer to the treatises of Lamé and Peschel as the authorities I have chiefly followed in Natural Philosophy; to Arago, Herschel, and Dick in Astronomy. To the treatises of M. Peschel and the astronomical works of Dr. Dick I am also indebted for many very excellent illustrations.

Those subjects, such as Caloric, which belong partly to Chemistry and partly to Natural Philosophy, and which, therefore, have been introduced in my text-book on the former subject, I have endeavored to present here in a different way, that those who use both works may have the advantage of seeing the same subject from dif-

ferent points of view. The laws of Undulations, now beginning to be recognized as an essential portion of this department of science, I have introduced as an abstract of what has been written on this subject by Peschel and Eisenlohr.

It will, therefore, be seen that the plan of this work is essentially the same as that of the Text-Book on Chemistry. It gives an abstract of the leading points of each lecture—three or four pages containing the matter gone over in the class-room in the course of an hour. The lengthened explanations and demonstrations which must always be supplied by the teacher himself are, therefore, except in the more difficult cases, here omitted. The object marked out has been to present to the student a clear view of the great facts of physical science, and avoid perplexing his mind with a multiplicity of details.

There are two different methods in which Natural Philosophy is now taught:—1st, as an experimental science; 2d, as a branch of mathematics. Each has its own peculiar advantages, and the public teacher will follow the one or the other according as it is his aim to store the mind of his pupil with a knowledge of the great facts of nature, or only to give it that drilling which arises from geometrical pursuits. From an extensive comparison of the advantages of these systems, I believe that the proper course is to teach physical science experimentally first—a conviction not only arising from considerations respecting the constitution of the human mind, the amount of mathematical knowledge which students commonly possess, but also from the history of these sciences. Why is it that the most acute mathematicians and metaphysicians the world has ever produced for two thousand years made so little advance in knowledge, and why have the last two centuries produced such a wonderful revolution in human affairs? It is from the lesson

first taught by Lord Bacon, that, so liable to fallacy are the operations of the intellect, experiment must always be the great engine of human discovery, and, therefore, of human advancement.

To teachers of Natural Philosophy I offer this book as a practical work, intended for the daily use of the class-room, and, therefore, so divided and arranged as to enable the pupil to pass through the subjects treated of in the time usually devoted to these purposes. A great number of wood cuts have been introduced, with a view of supplying, in some measure, the want of apparatus or other means of illustration. The questions at the foot of each page point out to the beginner the leading facts before him.

JOHN WILLIAM DRAPER.

University, New York,
July 16, 1847.

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INTRODUCTION.

CONSTITUTION OF MATTER.

LECTURE I.

PROPERTIES OF MATTER. — *The Three Forms of Matter.—Vapors.—The distinctive, essential, and accessory properties.—Extension.—Impenetrability.—Unchangeability.—Illustrations of Extension.—Methods of measuring small spaces.—The Spherometer.—Illustration of Impenetrability.—The Diving-Bell.*

MATERIAL substances present themselves to us under three different conditions. Some have their parts so strongly attached to each other that they resist the intrusion of external bodies, and can retain any shape that may be given them. These constitute the group of SOLIDS. A second class yields readily to pressure or movement, their particles easily sliding over one another; and from this extreme mobility they are unable of themselves to assume determinate forms, but always copy the shape of the receptacles or vessels in which they are placed—they are LIQUIDS. A third, yielding even more easily than the foregoing, thin and aerial in their character, and marked by the facility with which they may be compressed into smaller or dilated into larger dimensions, give us a group designated as GASES. Metals may be taken as examples of the first; water as the type of the second; and atmospheric air of the third of these states or conditions, which are called "the three FORMS of bodies."

In some instances the same substance can exhibit all three of these forms. Thus, when liquid water is cooled

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Under how many states do material substances occur? What are solids? What are liquids? What are gases? Give examples of each. What is the technical designation given to these states? Give an example of a substance that can assume all three forms.

A

to a certain degree, it takes on the solid condition, as ice or snow; and when its temperature is sufficiently raised, it assumes the gaseous state, and is then known as steam. Writers on Natural Philosophy have found it convenient, for many reasons, to introduce the term *Vapors*, meaning by that a gas placed under such circumstances that it is ready to assume the liquid state. As the steam of water conforms to this condition, it is therefore regarded as a vapor.

Under whichever of these forms material substances are presented, they exhibit certain properties: these are, first, Distinctive; second, Essential; third, Accessory.

There is a certain bright white metal passing under the name of Potassium, the *distinctive* character of which is, that, when thrown on the surface of water, it gives rise to a violent reaction, a beautiful violet-colored flame being evolved. A piece of lead, which, to external appearance, is not unlike the potassium when brought in contact with water, exhibits no such phenomenon, but, as every one knows, remains quietly, neither disturbing the water nor being acted upon by it.

Fig. 1.

Such distinctive qualities are the objects of a Chemist's studies. It belongs to his science to show how some gases are colored and others colorless; some supporters of combustion, while others extinguish burning bodies; how some liquids can be decomposed by Voltaic batteries and some by exposure to a red heat. The general doctrines of affinity, the modes in which bodies combine, and the characters of the products to which they give rise—all these belong to Chemistry.

But beyond these distinctive qualities of bodies, there are, as has been observed, certain other properties which are uniformly met with in all bodies whatever, and hence are spoken of as ESSENTIAL. They are,

Extension.
Impenetrability.
Unchangeability.

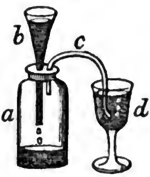
By EXTENSION we mean that all substances, whatever

Into what classes may the properties of bodies be divided? Give an example of distinctive properties. What is the object of the science of Chemistry? What are the essential properties of bodies? What is meant by extension? What by impenetrability?

their volume or figure may be, occupy a determinate portion of space. We measure them by three dimensions—length, breadth, and thickness.

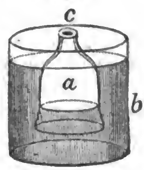
IMPENETRABILITY points out the fact that two bodies cannot occupy the same space at the same time. If a nail is driven into wood, it enters only by separating the woody particles from each other; if it be dropped into water, it does not penetrate, but displaces the watery particles: and even in the case of aerial bodies, through which masses can move with apparently little resistance, the same observation holds good. Thus, if we take a wide-mouthed bottle, *a*, *Fig.* 2, and insert through its cork a funnel, *b*, with a narrow neck, and also a bent tube, *c*, which dips into a glass of water, *d*, on pouring any liquid into the funnel, so that it may fall drop by drop into the bottle, we shall find, as this takes place, that air passes out, bubble after bubble, through the water in *d*. The air is, therefore, not penetrated by the water, but displaced.

Fig. 2.



The same fact may also be proved by taking a cupping-glass, *a*, *Fig.* 3, and immersing it, mouth downward, in a glass of water, *b*. If the aperture, *c*, of the cupping-glass be left open the air will rush out through it, and the water flow in below: but if it be closed by the finger, as the air can now no longer escape, the water is unable to enter and occupy its place.

Fig. 3.



Similar experiments establish the impenetrability of liquids by solids. If in a glass of water, *Fig.* 4, a leaden bullet is immersed, it will be seen that as the bullet is introduced the water rises to a higher level, showing, therefore, that a liquid can no more be penetrated by a solid than, as was seen in the former experiment, can a gas by a liquid. Two bodies cannot occupy the same space at the same time.

Fig. 4.

The third essential property of matter is its UNCHANGE-

Give an illustration that air is not penetrable by water. Give an illustration of the displacement of air by water. What is meant by unchangeability as a property of bodies?

ABILITY. This property may be looked upon as the foundation of Chemistry; and though there are many phenomena which we constantly witness which seem to contradict it, they form, when properly considered, striking illustrations of the great truth that material substances can neither be created nor destroyed, and that the distinctive qualities which appertain to them remain forever unchanged. The disappearance of oil in the combustion of lamps, the burning away of coal, the evaporation of water, when minutely examined, far from proving the perishability of matter, afford the most striking evidence of its duration. Nor is a solitary fact known in the whole range of Chemistry, Natural Philosophy, or Physiology, which lends the remotest countenance to the opinion that, either by the slow lapse of time or by any artificial processes whatever, can matter be created, changed, or destroyed. Even the bodies of men and animals, the structures of plants, and all other objects in the world of organization, which seem characterized by the facility with which they undergo unceasing and eventually total change, are no exception to the truth of this observation. The bodies which we possess to-day are made up of particles which have formed the bodies of other animals in former times, and which will again discharge the same duty for races that will hereafter come into existence.

As illustrations connected with the extension and impenetrability of matter, I may give the following instances:

We are frequently required to measure the dimensions of bodies; that is, to determine their length, breadth, or thickness. It is a much more difficult thing to do this accurately than is commonly supposed. It requires an artist of the highest skill to make a measure which is a foot or a yard in length, or which shall contain precisely a pint or a gallon. With a view of facilitating the measurement of bodies, a great many contrivances have been invented, such as verniers, spherometers, and screw machines of different kinds.

The spherometer, which is a beautiful contrivance for measuring the thickness of bodies, is constructed as fol-

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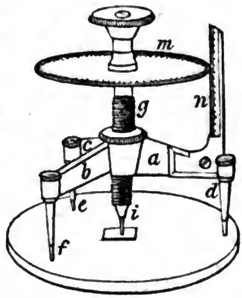
Is there any reason to believe that new material particles can be created by artificial processes, or old ones destroyed?

lows: It has three horizontal steel branches, *a*, *b*, *c*, *Fig.* 5, which form with each other angles of 120 degrees. From the extremities of these branches there proceed three delicate steel feet, *d*, *e*, *f*, and through the center, where the branches unite, a screw, *g*, the thread of which is cut with great precision, and which terminates in a pointed foot, *i*, passes. The head of this screw carries a divided circle, *m*. Now, suppose the instrument is placed on a piece of flat glass, it will be supported on its three feet, which are all in the same plane; but if in turning the screw we depress its point, *i*, beneath the plane of its feet, it can no longer stand with stability on the glass, but totters when it is touched, and emits a rattling sound. By altering the screw, therefore, we can give it such a position that both by the finger and the ear we discover that its point is level with the points *d*, *e*, *f*. Now let the object, the thickness of which is to be measured, be placed on the glass, and the screw turned until the instrument stands without tottering, it is obvious that its point must have been lifted through a distance precisely equal to the thickness of the object to be measured, and the movement of the head of the screw read off upon the scale, *n*, against which it works, indicates what that thickness is.

Fig 5.



This instrument, therefore, serves to show that in the measurement of small spaces, the senses of touch and hearing may often be resorted to with more effect than the eye. The spherometer is here introduced in connection with these general considerations respecting the extension of matter, as affording the student an illustration of the delicate methods we possess of determining the minutest dimensions of bodies.

As an illustration of the impenetrability of matter, the machine which passes under the name of the diving-bell

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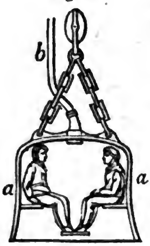
Describe the spherometer. What is its use? By what senses may we often form a better estimate of small spaces than by the eye?

may be mentioned. It consists of a vessel, *a*, *a*, *Fig.* 6, of any suitable shape, and heavy enough to sink in water when plunged with its mouth downward. Owing to the impenetrability of the air the water is excluded from the interior, or only finds access to such an extent as corresponds to the pressure of the depth to which it is sunk. Light is admitted to the bell through thick pieces of glass in its top, and a constant stream of fresh air thrown into it from a tube, *b*, and forcing-pump above, the atmosphere in the inside being suffered to escape through a stop-cock as it becomes vitiated by the respiration of the workmen. Diving-bells are extensively resorted to in submarine architecture, and for the recovery of treasure lost in the sea.

Fig. 6.



LECTURE II.

PROPERTIES OF MATTER.—*The Accessory Properties of Matter.—Compressibility.—Expansibility.—Elasticity.—Limit of Elasticity.—Illustrations of Divisibility.—Porosity and interstitial spaces.—Weight.*

PHYSICAL FORCES.—*Attractive and Repulsive Forces.—Molecular Attraction.—Gravitation.—Cohesion.—Constitution of Matter.*

HAVING disposed of the *essential*, we pass next to a consideration of the *accessory properties* of matter. They are,

Compressibility.
Expansibility.
Elasticity.
Divisibility.
Porosity.
Weight.

That substances of all the three forms are compressible is capable of easy proof. In the process of coining, pieces of metal are exposed to powerful pressure between the steel dies, so that they become much denser than be-

Describe the diving-bell. On what principle does it act? Why must the air in its interior be renewed from time to time? What are the accessory properties of matter?

fore. By inclosing water or any other liquid in a strong vessel, and causing a piston, driven by a screw, to act upon it, it may be reduced to a less space, and gaseous substances, such as atmospheric air when inclosed in an India-rubber bag, or even a bladder, may be compressed by the hands.

Under the influence of heat all substances expand. This may be proved for such solids as metals by the apparatus represented in *Fig.* 7. It consists of a stout board, *a b*, on which are fastened two brass uprights, *c, d*, with notches cut in them so as to receive the ends of a metallic bar, *e*. This bar is slightly shorter than the whole distance between the notches, so that when it is set in its place it can be moved backward and forward, and emits a rattling sound. But if boiling water be poured upon it, it expands and occupies the whole distance, and can no longer be moved. The expansion of liquids is well shown in the case of common thermometers, which contain either quicksilver or spirits of wine—those substances occupying a greater volume as their temperature rises. The air thermometer proves the same thing for gases.

Fig. 7.

By elasticity we mean that quality by which bodies, when their form has been changed, endeavor to recover their original shape. In this respect there are great differences. Steel, ivory, India-rubber are highly elastic, and lead, putty, clay less so. Perfectly elastic bodies resist the action of disturbing causes without any ulterior change: thus a quantity of atmospheric air, compressed into a copper globe, recovers its original volume as soon as the pressure is removed, though it may have been shut up for years. By the *limit of elasticity* we mean the smallest force which is required to produce a permanent disturbance in the structure of an imperfectly elastic body. No solid is perfectly elastic. An iron wire, drawn a little aside, recovers its original straightness; but if more violently bent, it takes a permanent set, because its limit of elasticity is overpassed. The elasticity of a given

Give proofs that solids, liquids, and gases are all compressible. How can it be proved that solids, liquids, and gases are expansible? What is meant by elasticity? Give examples of highly elastic and less elastic bodies. What is meant by the limit of elasticity?

substance can often be altered by mechanical processes, such as by hammering, or by heating and cooling, as in the process of tempering.

The divisibility of matter may be proved in many ways. By various mechanical processes metals may often be reduced to an extreme degree of tenuity: thus it is said that gold-leaf may be beaten out until it is only $\frac{1}{200000}$ of an inch thick. By chemical experiments a grain of copper or of iron may be divided into many millions of parts. For certain purposes artists have ruled parallel lines upon glass, with a diamond point, so close to each other that ten thousand are contained in a single inch. The odors which are exhaled by strong-smelling perfumes, as musk, will for years together infect the air of a large room, and yet the loss of weight by the musk is imperceptible. Again, there are animals whose bodies are so minute that they can only be seen by the aid of the microscope. The siliceous shells of such infusorials occur in many parts of the earth as fossils. Ehrenberg has shown that Tripoli, a mineral used in the arts, is made up of these—a single cubic inch of it containing about forty-one thousand millions—that is, about fifty times as many individuals as there are of human beings on the face of the globe.

As substances of all kinds may be reduced to smaller dimensions, either by pressure or the influence of cold, and as it is impossible for two particles to occupy the same place at the same time, or even for one of them partially to encroach on the position occupied by the other, it necessarily follows that there must be pores or interstices even in the densest bodies. Thus quicksilver will readily soak into the pores of gold, and gases ooze through India-rubber. Writers on Natural Philosophy usually restrict the term "pore" to spaces which are visible to the eye, and designate those minute distances which separate the ultimate particles of bodies by the term "interstices."

All bodies have weight or gravity. It is this which

How may the elasticity of a given substance be changed? Give some illustrations of the great divisibility of matter, derived from mechanical, chemical, physiological, and geological facts. How may it be proved that all bodies are porous? What is meant by a "pore," and what by "interstices?"

causes them to fall, when unsupported, to the ground, or when supported, to exert pressure upon the supporting body. Nor is this property limited to terrestrial objects; for in the same way that an apple tends to fall to the earth, so too does the moon; and all the planets gravitate toward each other and toward the sun. It was the consideration of this principle that led M. Leverrier to the discovery of a new planet beyond Uranus—this latter star being evidently disturbed in its movements by the influences of a more distant body hitherto unknown.

Of Physical Forces.—All changes taking place in the system of nature are due to the operation of forces. The attractive force of the earth causes bodies to fall, and a similar agency gives rise to the shrinking of substances—their parts coming closer together when they are exposed to the action of cold. In like manner, when an ivory ball is suffered to drop on a marble slab, its particles, which have been driven closer to one another by the force of the blow, instantly recover their original positions by repelling one another; that is to say, through the agency of a repulsive force. Of the nature of forces we know nothing. Their existence only is inferred from the effects they produce; and according to the nature of those effects, we divide them into Attractive and Repulsive forces—the former tending to bring bodies closer together, the latter to remove them farther apart.

It has been found convenient to divide attractive forces into three groups, according as the range of their action or the circumstances of their development differ. When the attractive influence extends only to a limited space, it is spoken of as *molecular attraction;* but the attraction of gravitation is felt throughout the regions of space. By cohesion is meant an attractive influence called into existence when bodies are brought to touch one another. It is to be understood that these are only conventional distinctions; and it is not improbable that all the phenomena of attraction are due to the agency of one common cause.

Chemists have shown that, in all probability, material substances are constituted upon one common type. They

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What is meant by weight or gravity? Is it limited to terrestrial objects? What is meant by forces? How many varieties of them are there? Into what three groups are attractive forces divided? What is the distinction between them?

are made up of minute, indivisible particles, called atoms, which are arranged at variable distances from each other. These distances are determined by the relative prevalence of attractive and repulsive forces, resident in or among the particles themselves; and so too is the form of the resulting mass. If the cohesive predominates over the repulsive force, a solid body is the result; if the two are equal it is a liquid, and if the repulsive prevails it is a gas.

There are many reasons which lead us to suppose that the repulsive force, which thus tends to keep the particles of matter asunder, is the agent otherwise known as heat. Whenever the temperature of a body rises it enlarges in volume, because its constituent particles move from each other, and on the temperature falling the reverse effect ensues. If, as many very eminent philosophers believe, heat and light are in reality the same agent, it follows, by a necessary consequence, as will be gathered from what we shall hereafter have to say on optics, that the atoms of bodies vibrate unceasingly, and that instead of there being that perfect quiescence among them which a superficial examination suggests, all material substances are the seat of oscillatory movements, many millions of which are executed in the space of a single second of time; the number increasing as the temperature rises, and diminishing as it falls.

What is the true constitution of material substances? What are the forces residing among the particles of bodies? What are the conditions which determine the solid, liquid, and gaseous forms? What is probably the nature of the force of molecular repulsion? If light and heat are the same agent, what is the condition of the particles of bodies?

NATURAL PHILOSOPHY.

PROPERTIES OF THE AIR.

PNEUMATICS.

LECTURE III.

Natural Philosophy.—*Observations on this branch of Science.*

Pneumatics.—*General Relations of the Air.—Its connection with Motion and Organization.—Limited Extent.—Constitution.—Compressibility.—Causes which Limit the Atmosphere.—Its Variable Densities.—Proportionality of its Elastic Force and Pressure.*

A very superficial knowledge of those parts of the world to which man has access readily leads to their classification under three separate heads—the air, the sea, and the solid earth. This was recognized in the infancy of science, for the four elements of antiquity were the divisions which we have mentioned, and fire.

Natural Philosophy or Physical Science, which, in its extended acceptation, means the study of all the phenomena of the material world, may commence its investigations with any objects or any facts whatever. By pursuing these, in their consequences and connections, all the discoveries which the human mind has made in this department of knowledge might successively be brought forward. But when we are left to select at pleasure our point of commencement, it is best to follow the most natural and obvious course. All the advances made in our times by the most eminent philosophers, and our powers of appreciating and understanding them, depend on clearness of perception of the great fundamental facts of science—a perspicuity which can never arise from mere abstract reasonings or from the unaided operations of the

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What were the elements of the ancients? What is Natural Philosophy?

human intellect, but which is the natural consequence of a familiarity with *absolute facts.* These serve us as our points of departure, and in the more difficult regions of science they are our points of reference—often by their resemblances, and even by their differences, making plain what would otherwise be incomprehensible, and spreading a light over what would otherwise be obscure.

In the three divisions of material objects, which are so strikingly marked out for us by nature, we find traits that are eminently characteristic. All our ideas of permanence and duration have a convenient representation in the solid crust of the earth, the mountains, and valleys, and shores of which retain their position and features unaltered for centuries together. But the air is the very type and emblem of variety, and the direct or indirect source of almost every motion we see. It scarce ever presents to us, twice in succession, the same appearance; for the winds that are continually traversing it are, to a proverb, inconstant, and the clouds that float in it exhibit every possible color and shape. It is, in reality, the grand origin or seat of all kinds of terrestrial motions. Storms in the sea are the consequences of storms in the air, and even the flowing of rivers is the result of changes that have transpired in the atmosphere.

But the interest connected with it is far from ending here. The atmosphere is the birthplace of all those numberless tribes of creation which constitute the vegetable and animal world. It is of materials obtained from it that plants form their different structures, and, therefore, from it that all animals indirectly derive their food. It is the nourisher and supporter of life, and in those processes of decay which are continually taking place during the existence of all animals, and which after death totally resolve their bodies into other forms, the air receives the products of those putrefactive changes, and stores them up for future use. And it is one of the most splendid discoveries of our times, that these very products which arise from the destruction of animals are those which are used to support the life and develop the parts of plants. They pass, therefore, in a continual circle, now belonging to the vegetable, and now to the animal world;

What appears to be the leading characteristic of the atmosphere? What are its relations to the organic world?

they come from the air, and to it they again are restored.

It is not, therefore, the beautiful blue color which the air possesses, and which people commonly call the sky, or the points of light which seem to be in it at night, or the moving clouds which overshadow it and give it such varied and fantastic appearances, or even those more imposing relations which bring it in connection with the events of life and death, which alone invest it with a peculiar claim on the attention of the student. Connected as it is with the commonest every-day facts, it furnishes us with some of our most appropriate illustrations—those simple facts of reference of which I have already spoken, and to which we involuntarily turn when we come to investigate the more difficult natural phenomena.

Astronomical considerations show that the atmosphere does not extend to an indefinite region, but surrounds the earth on all sides to an altitude of about fifty miles. Compared with the mass of the earth its volume is quite insignificant; for as it is nearly four thousand miles from the surface to the center of the earth, the whole depth of the atmosphere is only about one-eightieth part of that distance. Upon a twelve-inch globe, if we were to place a representation of the atmosphere, it would have to be less than the tenth of an inch thick.

Seen in small masses, atmospheric air is quite colorless and perfectly transparent. Compared with water and solid substances, it is very light. Its parts move among one another with the utmost facility. Chemists have proved that it is not, as the ancients supposed, an elementary body, but a mixture of many other substances. It is enough at present for us to know that its leading constituents are two gases, which exist in it in fixed quantities—they are oxygen and nitrogen—but other essential ingredients are present in a less proportion, such as carbonic acid gas, and the vapor of water.

Atmospheric air is taken by natural philosophers as the type of all gaseous bodies, because it possesses their general properties in the utmost perfection. Individual gases have their special peculiarities—some, for

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What is the altitude of the atmosphere? What comparison does this bear to the mass of the earth? What are its general properties? What bodies constitute it? Of what class is it the type?

example, are yellow, some green, some purple, and some red.

The first striking property of atmospheric air which we encounter, is the facility with which the volume of a given quantity of it can be changed. It is highly compressible and perfectly elastic. A quantity of it tied tightly up in a bladder or India-rubber bag, is easily forced, by the pressure of the hand, into a less space. The materiality of the air, and its compressibility, are simultaneously illustrated by the experiment of the diving-bell, described under *Fig*. 6. A vessel forced with its mouth downward under water, permits the water to enter a little way, because the included air goes into smaller dimensions under the pressure; but as soon as the vessel is again brought to the surface of the water, the air within it expands to its original bulk.

Fig. 8.

This ready compressibility and expansibility may be shown in many other ways. Thus, if we take a glass tube, *Fig*. 8, with a bulb *c*, at its upper end, the lower end being open and dipping into a vessel of water, *d*, and having previously partially filled the tube with water to the height, *a*, it will be found, on touching the bulb with snow, or by pouring on it ether, or by cooling it in any manner, that the included air collapses into a less bulk. It is therefore compressible, and on warming the bulb with the palm of the hand, the air is at once dilated.

It is this quality of easy expansibility and compressibility which distinguishes all gaseous substances from solids and liquids. It is true the same property exists in them, but then it is to a far less degree. On the hypothesis that material bodies are formed of particles which do not touch one another, but are maintained by attractive and repulsive forces at determinate distances, it would appear that, in a gas like atmospheric air, the repulsive quality predominates over the attractive; while in solids the attractive force is the most powerful, and in liquids the two are counterbalanced.

Again, as respects relative weight, the gases, as a tribe, are by far the lightest of bodies; and, indeed, it is

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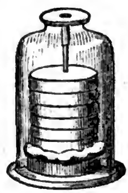
How may it be proved to be compressible? What does the diving-bell prove? Describe the experiment, *Fig*. 8. In gaseous bodies does the attractive or repulsive force predominate?

among them that we find the lightest substance in nature —hydrogen gas. They are, moreover, the only *perfectly elastic* substances that we know. Thus, a quantity of atmospheric air compressed into a metal reservoir will regain its original volume the moment it has the opportunity, no matter how great may be the space of time since it was first shut up.

Fig. 9.

Under a relaxation of pressure this perfect elasticity displays itself in producing the expansion of a gas. If a bladder partially full of atmospheric air be placed under an air-pump receiver, as the pressure is removed it dilates to its full extent, and might even be burst by the elastic force of the air confined within. The force with which this expansion takes place is very well displayed by putting the bladder in a frame, as shown in *Fig.* 10, and loading it with heavy weights; as it expands by the spring of the air, it lifts up all the weights.

Fig. 10.



If we were to imagine a given volume of gas placed in an immense vacuum, or under such circumstances that no extraneous agency could act upon it, it is very clear that its expansion would be indefinitely great—the repulsive force of its own particles predominating over their attraction, and there being nothing to limit their retreat from one another. But when a gaseous mass surrounds a solid nucleus, the case is different —an expansion to a determinate and to a limited extent is the result. And these are the circumstances under which the earth and every planet surrounded by an elastic atmosphere exists; for in the same way that our globe compels an unsupported body to fall to its surface, and makes projectiles as bomb-shells and cannon-shot—no matter what may have been the velocity with which they were urged—return to the ground, so the same attractive force restrains the indefinite expansion of the air, and keeps the atmosphere, instead of diffusing away into empty space, imprisoned all round.

Besides this cause—gravitation to the earth—a second

Are gases perfectly elastic? What does experiment *Fig.* 9 prove? What would happen to a volume of gas placed in an indefinite vacuum? What limits the atmosphere to the earth?

one, for the limited extent of the atmosphere, may also be assigned—contraction—arising from cold. Observation has shown that, as we rise to greater altitudes in the air, the cold continually increases; and gases, in common with all other forms of body, are condensed by cold. The attempt at unlimited expansion which the atmosphere, by reason of its gaseous constitution exerts, is, therefore, kept in bounds by two causes—the attractive force of the earth and cold—and accordingly its altitude does not exceed fifty miles.

From the circumstance that air is thus a compressible body, we might predict one of the leading facts respecting the constitution of the atmosphere—it is of unequal densities at different heights. Those portions of it which are down below have to bear the weight of the whole superincumbent mass; but this weight necessarily becomes less and less as we advance to regions which are higher and higher; for in those places, as there is less air to press, the pressure must be less. And all this is verified by observation. The portions which rest on the ground are of the greatest density, and the density steadily diminishes as we rise. Moreover, a little consideration will assure us that there is a very simple relation between the pressure which the air exerts and its elastic force. Consider the condition of things in the air immediately around us: if its elastic force were less, the weight of the superincumbent mass would crush it in; if greater, the pressure could no longer restrain it, and it would expand. It follows, therefore, in the necessity of the case, that the elastic force of any gas is neither greater nor less, but precisely equal to the pressure which is upon it.

What is the agency of cold in this respect? Why is the atmosphere of unequal density at different heights? What relation is there between its pressure and its elastic force?

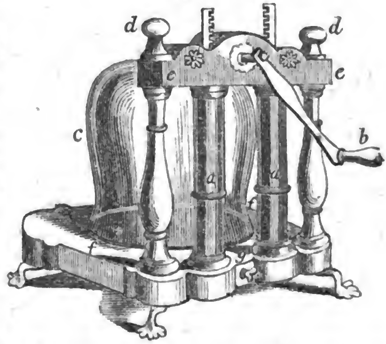
LECTURE IV.

WEIGHT AND PRESSURE OF THE AIR.—*Description of the Air-pump.—Its Action.—Limited Exhaustion.—Fundamental fact that Air has weight.—Relative weight of other Gases.—Weight gives rise to Pressure.—Experiments illustrating the Pressure of the Air.*

IN the year 1560, Otto Guericke, a German, invented an instrument which, from its use, passes under the name of the air-pump, and exhibited a number of very striking experiments before the Emperor Ferdinand III. This incident forms an epoch in physical science.

Otto Guericke's instrument was imperfect in construction and difficult of management. The apparatus required to be kept under water. More convenient machines have, therefore, been devised. The following is a description of one of the most simple: Upon a metallic basis, *f f*, *Fig.* 11, are fastened two exhausting syringes, *a a*, which are worked by means of a handle, *b*, the two screw columns, *d d*, aided by the cross-piece, *e e*, tightly compressing them into their places. A jar, *c*, called a receiver, the mouth of which is carefully ground true, is placed on the plate of the pump, *f f*, which is formed of a piece of metal or glass ground quite flat. This pump-plate is perforated in its center, from which air-tight passages lead to the bot-

Fig. 11.

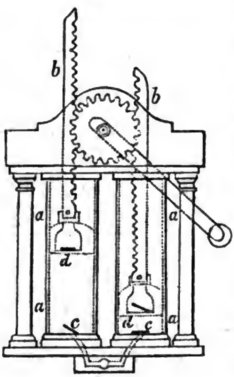


When and by whom was the air-pump invented? Give a description of its general external appearance. What is the receiver? What is the pump-plate? What passages lead from the center of the plate? What is the use of the screw *g*?

tom of each syringe, and when the handle, *b*, is moved the syringes withdraw the air from the interior of the jar. From the same central perforation there is a third passage, which can be opened or closed by the screw at *g*, so that when the experiments are over, by opening it the air can be readmitted into the interior of the receiver.

So far as its exterior parts are concerned, this air-pump consists of a pair of syringes worked by a handle, and producing exhaustion of the interior of a jar, with a vent which can be closed or opened for the readmission of air.

Fig. 12.



The syringes are constructed exactly alike. The glass model represented in *Fig.* 12 exhibits their interior; each consists of a cylinder, *a a*, the interior of which is made perfectly true, so that a piston or plunger, *d*, introduced at the top may be pushed to the bottom, and, indeed, work up and down without any leakage. There is a hole made through the piston, *d*, and over it a valve is laid. This consists of a flexible piece of membrane, as leather, silk, &c., which being placed on the aperture opens in one direction and closes in the other. Such a valve is in the piston, and there is another one, *c*, resting on an aperture in the bottom of the cylinder.

To understand the action of this instrument, let us suppose a glass globe full of atmospheric air to be fastened air-tight to the bottom of such a syringe, and the piston then lifted to the top of the cylinder. As it moves without leakage, it would evidently leave a vacuum below it were it not that the air in the globe, exerting its elastic force, pushes up the valve *c*, and expands into the cylinder. In this way, therefore, by the upward movement of the piston, a certain quantity of air comes out of the globe and fills the cylinder. The piston is now depressed: the moment it begins to descend, the valve *c*, which leads

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What are the parts of each syringe? How many valves has it? Which way do they open? Describe what takes place during the upward motion of the piston. What takes place during the downward motion?

into the globe shuts; and now as the piston comes down it condenses the air below it, and as this air is condensed it resists exerting its elastic force. The piston-valve, *d*, under these circumstances, is pushed open, and the compressed air gets away into the atmosphere. As soon as the piston has reached the bottom of the cylinder all the air has escaped, and the process is repeated precisely as before. The action in the syringe is, therefore, to draw out from the globe a certain quantity of air at each upward movement, and expel this quantity into the air at each downward movement.

For reasons connected with the great pressure of the air, and also for expediting the process of exhaustion, two syringes are commonly used. To their pistons are attached rods which terminate in racks, *b b;* between these there is placed a toothed wheel, which is turned on its axis by the handle, its teeth taking into the teeth of the racks. When the handle is set in motion and the wheel made to revolve, it raises one of the pistons, and at the same time depresses the other. The ends of these racks are seen in *Fig.* 12. The wheel is included in the transverse wooden bar, *e e*, *Fig.* 11.

By the aid of this invaluable machine numerous striking and important experiments may be made. The form described here is one of the most simple, and by no means the most perfect. For the higher purposes of science more complicated instruments have been contrived, in which, with the utmost perfection of workmanship, the valves are made to open by the movements of the pump itself, and do not require to be lifted by the elastic force of the air. In such pumps a far higher degree of rarefaction can be obtained.

No air-pump, no matter how perfect it may be, can ever make a perfect vacuum, or withdraw all the air from its receiver. The removal of the air depends on the expansion of what is left behind, and there must always be that residue remaining which has forced out the portion last removed by the action of the syringes.

The fundamental fact in the science of Pneumatics is, *that atmospheric air is a heavy body*, and this may be

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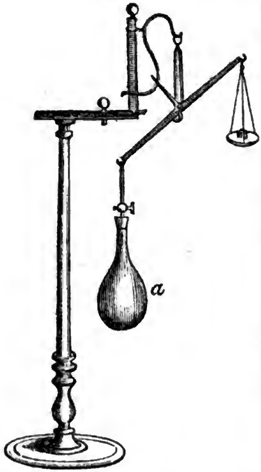
How are the pistons moved by the rack? What contrivances are introduced in the more perfect air-pumps? Can any of these instruments make a perfect vacuum? What is the cause of this?

proved in a very satisfactory manner by the aid of the

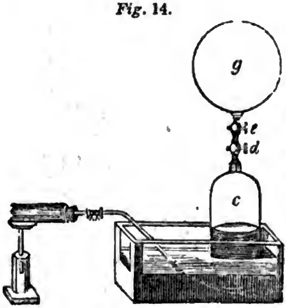
Fig. 13.



pump. Let there be a glass flask, *a*, *Fig.* 13, the mouth of which is closed with a stop-cock, through which the air can be removed. If from this flask we exhaust all the air, and then equipoise it with weights at a balance as soon as the stop-cock is opened and the air allowed to rush in the flash preponderates. By adding weights in the opposite scale, we can determine how much it requires to bring the balance back to equilibrio, and therefore what is the weight of a volume of air equal to the capacity of the flask.

Upon the same principles we can prove that all gases, as well as atmospheric air, have weight. It is only requisite to take the exhausted flask, and having counterpoised it as before,

Fig. 14.



screw it on to the top of a jar, *c*, *Fig.* 14, containing the gas to be tried. On opening the stop-cocks, *e d*, the gas flows out of the jar and fills the flask, which, being removed, may be again counterpoised at the balance, and the weight of the gas filling it determined. There are very great differences among gases in this respect. Thus, if we take one hundred cubic inches of the following they will severally weigh:

Hydrogen	2·1 grains.
Nitrogen	30·1 "
Atmospheric air	31·0 "
Carbonic acid	47·2 "
Vapor of Iodine	269·8 "

What is the fundamental fact in Pneumatics? How may the weight of the air be proved? How do other gases compare with it in this respect? Mention some of them.

From the fact that the air has weight, it necessarily follows that it exerts pressure on all those portions that are in the lower regions, having to sustain the weight of the masses above. And not only does this hold good as respects the aerial strata themselves, it also holds for all objects immersed in the air. In most cases, the resulting pressure is not detected, because it takes effect equally in all directions, and pressures that are equal and opposite mutually neutralize each other.

But when by the air-pump we remove the pressure from one side of a body, and still allow it to be exerted on the other, we see at once abundant evidence of the intensity of this force. Thus, if we take a jar, *Fig.* 15, open at both ends, and having placed it on the pump-plate, lay the palm of the hand on the mouth of it; on exhausting the air the hand is pressed in firm contact with the jar, so that it cannot be lifted without the exertion of a very considerable force.

Fig. 15.

In the same way, if we tie over a jar a piece of bladder, and allow it to dry, it assumes, of course, a perfectly horizontal position; but on exhausting the air within very slightly, it becomes deeply depressed, and is soon burst inward with a loud explosion. This simple instance illustrates, in a very satisfactory way, the mode in which the pressure of the air is thus rendered obvious; for so long as the jar was not exhausted, and had air in its interior, the downward pressure of the atmosphere could not force the bladder inward, nor disturb its position in any manner: for any such disturbance to take place the pressure must overcome the elastic force of the air within, which resists it, pressing equally in the opposite way But on the removal of the air from the interior, the pressure above is no longer antagonized, and it takes effect at once by crushing the bladder.

Fig. 16.

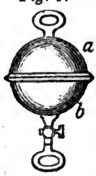
Why does the air exert pressure? What follows on removing the pressure from one side of a body? Describe the experiment in *Figs.* 15 and 16. Why is not the bladder crushed in until the air is exhausted?

LECTURE V.

The Pressure of the Air.—*The Magdeburg Hemispheres.—Water supported by Air.—The Pneumatic Trough.*

The Barometer.—*Description of this Instrument.—Cause of its Action.—Different kinds of Barometers.—Measurement of Accessible Heights.*

Fig. 17



Many beautiful experiments establish the fact that the atmosphere presses, not only in the downward direction, but also in every other way. Thus, if we take a pair of hollow brass hemispheres, *a b*, *Fig.* 17, which fit together without leakage, by means of a flange, and exhaust the air from their interior through a stop-cock affixed to one of them, it will be found that they cannot be pulled apart, except by the exertion of a very great force. Now it does not matter whether the handles of these hemispheres are held in the position represented in the figure, or turned a quarter way round, or set at any angle to the horizon they adhere with equal force together; and the same power which is required to pull them asunder in the vertical direction, must also be exerted in all others. This, therefore, proves that the pressure of the air takes effect equally in every direction, whether upward, or downward, or laterally.

Fig. 18.

In *Fig.* 18 a very interesting experiment is represented. We take a jar, *a*, an inch or two wide and two or three feet long, closed at one end and open at the other, and having filled it entirely with water, place over its mouth a slip of writing paper, *b*. If now the jar be inverted in the position represented in the figure, it will be seen that the column of fluid is supported, the paper neither dropping off nor the water flowing out. This remarkable result illustrates the doctrine of the upward pressure of the air. Nor does it even require that

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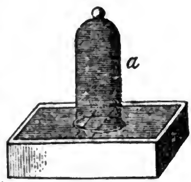
Prove that the air presses equally every way. Describe the apparatus in *Fig.* 18. Why does not the paper fall from the mouth of the jar?

a piece of paper should be used provided the glass has the proper form. Thus, let there be a bottle, *a*, *Fig*. 19, in the bottom of which there is a large aperture, *b*. If the bottle be filled with water, and its mouth closed by the finger, the water will not flow out, but remain suspended. And that this result is due to the upward pressure of the air is proved by moving the finger a little on one side, so as to let the air exert its pressure on the top as well as the bottom of the water, which immediately flows out.

Fig. 19.

If we take a jar, *a*, *Fig*. 20, and having filled it full of water, invert it as is represented, in a reservoir or trough: for the reason explained in reference to *Fig*. 18, the water will remain suspended in the jar. Such an arrangement forms the pneumatic trough of chemists. It enables them to collect the various gases without intermixture with atmospheric air; for if a pipe or tube through which such a gas is coming be depressed beneath the mouth of the jar *a*, so that the bubbles may rise into the jar, they will displace the water, and be collected in the upper part without any admixture.

Fig. 20.



If in this experiment we use mercury instead of water, the same phenomenon ensues—the mercury being supported by the pressure of the air. Now it might be inquired, as the atmosphere only extends to a certain altitude, and therefore presses with a weight which, though great, must necessarily be limited, whether that pressure could sustain a column of mercury of an unlimited length? If we take a jar a yard in length, and fill it with mercury, and invert it in a trough, it will be seen that the mercury is not supported, but that it settles from the top and descends until it reaches a point which is about thirty inches above the level of the mercury in the trough. Of course, as nothing has been admitted, there must be a vacant

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Will the same take place without any paper? Prove that it is due to the upward pressure of the air. What is the pneumatic trough? On what principle does it depend? Will the same take place if mercury is used instead of water? What takes place when the jar is more than thirty inches high?

space or vacuum between the top of the mercury and the top of the jar.

Fig. 21.

This experiment which, as we are soon to see, is a very important one, is commonly made with a tube, *a b*, *Fig.* 21, instead of a jar—the tube being more manageable and containing less mercury. It should be at least thirty-two inches long, and being filled with quicksilver, may be inverted in a shallow dish containing the same metal, *c*. It is convenient to place at one side of the tube a scale, *d*, divided into inches, these inches being counted from the level of the mercury in the dish, *c*. Such an instrument is called a Barometer, or measurer of the pressure of the air.

Let us briefly investigate the agencies which operate in the case of this instrument. If, having closed the mouth of the tube *b* with the finger, we lift it out of the dish *c*, it will be found that we must exert a considerable degree of force in order to sustain the column of mercury, which presses against the finger with its whole weight, and tends to push it away. Consequently, the mercury is continually exerting a tendency to flow out, and therefore two forces are in operation: on the one hand, the weight of the mercury attempting to flow out of the tube into the dish; and on the other, the weight or pressure of the atmosphere attempting to push the mercury up in the tube.

Fig. 22.

If the pressure of the air were greater, it would push the mercury higher; if less, the mercury would flow out to a corresponding extent. Thus, the length of the mercurial column equilibrates the pressure of the air, and we therefore say that the atmospheric pressure is equal to so many inches of mercury.

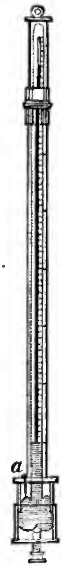
That the whole thing depends on the pressure of the air may be beautifully proved by putting the barometer under a tall air-pump receiver, as represented in *Fig.* 22, and exhausting. As the pressure of the air is reduced the mercurial column falls; and if it were possible to make a per-

How is this experiment commonly made? Describe a barometer. What are the forces which operate in this instrument? What does the mercurial column equilibrate? What is it equal to? How may it be proved to depend on the pressure of the air?

fect vacuum by such means, the mercury would sink in the tube to its level in the dish. On readmitting the air the mercury rises again, and when the original pressure is regained it stands at the original level.

There are many different forms of barometers, such as the straight, the syphon, &c., but the principle of all is the same. The scale must uniformly commence at the level of the mercury in the reservoir. Now it is plain that this level changes with the height of the column; for if the metal flows out of the tube it raises the level in the reservoir, and *vice versa.* In every perfect barometer, means, therefore, should be had to adjust the beginning of the scale to the level for the time being. In some barometers, as in that represented in *Fig.* 23, this is done by having the mercury in a cistern with a movable bottom, and by turning the screw V, the level can be precisely adjusted to that of the ivory point, *a*.

Fig. 23.



A barometer kept in the same place undergoes variations of altitude, some of which are regular and others irregular. The former, which depend on diurnal tides in the atmosphere, analogous to tides in the sea, occur about the same time of the day—the greatest depression being commonly about four in the morning and evening, and the greatest elevation about ten in the morning and night. In summer, however, they occur an hour or two earlier in the morning, and as much later at night. The irregular changes depend on meteorological causes, and are not reduced as yet to any determinate laws. In amount they are much more extensive than the former, extending from the twenty-seventh to more than the thirtieth inch, while those are limited to about the tenth of an inch.

A very valuable application of the barometer is for the determination of accessible heights. The principle upon which this depends is simple—the barometer necessarily

What would ensue if a perfect vacuum could be made? What takes place on readmitting the air? From what point should the scale of the barometer commence? What are the regular barometric changes? What is the extent of the irregular ones? How is the barometer applied to the measurement of heights?

standing at a lower point as it is carried to a higher position. In practice it is more complicated, and to obtain exact results various methods have been given by Laplace, Baily, Littrow, and others.

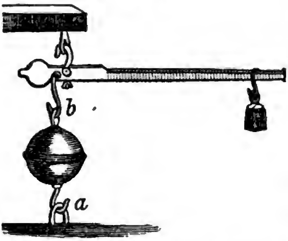
LECTURE VI.

THE PRESSURE OF THE AIR.—*Measure of the Force with which the Air presses.—Different Modes of Estimating it.—Experiments Illustrating this Force.*

ELASTICITY OF THE AIR.—*Experimental Illustrations.—The Condenser.*

HAVING, in the preceding lecture, explained the cause and illustrated the pressure of the air, we proceed in the next place to determine its actual amount.

Fig. 24.



There are many ways in which this may be done. The following is simple: Take a pair of Magdeburg hemispheres, the area of the section of which has been previously determined in square inches; exhaust them as perfectly as possible at the pump; and then, fastening the lower handle, *a*, to a firm support, hang the other, *b*, *Fig.* 24, to the hook of a steelyard, and move the weight until the hemispheres are pulled apart. It will be found that this commonly takes place when the weight is sufficient to overcame a pressure of fifteen pounds on every square inch.

This may serve as an elementary illustration, but there are other methods much more exact. Thus, by the barometer itself we may determine the value of the pressure with precision. If we had a barometer which was exactly one square inch in section, and weighed the quantity of mercury it contained at any given time, it would

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What may the Magdeburg hemisphere be made to prove? How may the same be proved by the barometer? What is the pressure of the air on one square inch?

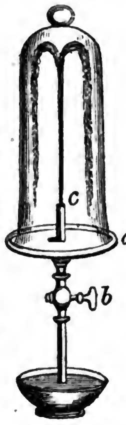
give us the value of the atmospheric pressure on one square inch, because the weight of the mercury is equal to the pressure of the air. And by calculation we can, in like manner, obtain it from tubes of any diameter.

The phenomena of the barometer teach us that this pressure is not always the same, but it undergoes variations. It is commonly estimated at fifteen pounds on the square inch.

There are two other ways in which the value of the pressure of the air is stated. It is equal to a column of mercury thirty inches in length, or to a column of water thirty-four feet in length.

We are now able to understand the reason of the great effects to which the pressure of the air may give rise. In most instances these effects are neutralized by countervailing pressures. Thus, the body of a man of ordinary size has a surface of about two thousand square inches, the pressure upon which is equal to thirty thousand pounds. But this amazing force is entirely neutralized, because, as we have seen, the atmospheric pressure is equal in all directions, upward, downward, and laterally. All the cavities and the pores of the body are filled with air, which presses with an equal force.

Fig. 25.



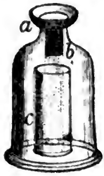
The following experiments may further illustrate the general principle of atmospheric pressure:

On a small, flat plate, *a*, *Fig.* 25, furnished with a stop-cock, *b*, which terminates in a narrow pipe, *c*, let there be placed a tall receiver from which the air is to be exhausted by the pump. The stop-cock *b* being closed, and the instrument being removed from the pump, *b* is to be opened, while the lower portion of its tube dips into a bowl of water. Under these circumstances the water is pressed up in a jet through *c*, and forms a fountain in vacuo.

On the top of a receiver, *Fig.* 26, let there be cemented, air-tight, a cup of wood,

What is the length of an equivalent column of mercury? What is it in the case of water? What amount of pressure is there on the body of a man? By what is this counteracted? Describe the fountain in vacuo. How may mercury be pressed through the pores of wood?

Fig. 26.

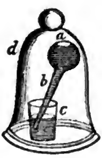


a, terminating in a cylindrical piece, *b*, the pores of which run lengthwise. Beneath this let there be placed a tall jar, *c*. Now, if the wooden cup be filled with quicksilver, the jar being previously placed on the pump, and exhaustion made, the metal will be pressed through the pores of the wood and descend in a silver shower. The jar, *c*, should be so placed as to prevent any of the quicksilver getting into the interior of the pump.

Fig. 27.

There are many substances which exist in the liquid condition, merely because of the pressure of the air. Take a glass tube, A, *Fig.* 27, closed at one end and open at the other, and having filled it with water, invert it in a jar, B; introduce into it now a little sulphuric ether, which will rise, because of its lightness, to the top of the tube, at *a*. Place the apparatus beneath the receiver of the air-pump, and exhaust. The ether will now be seen to abandon the liquid and assume the gaseous form, filling the entire tube and looking like air. On allowing the pressure again to take effect, it again relapses into the liquid form.

Fig. 28.



The following experiments illustrate the elasticity of the air:

Take a glass bulb, *a*, *Fig.* 28, which has a tube, *b*, projecting from it, the open extremity of which dips beneath some water in a cup, *c*; the tube and the bulb being likewise full of water, except a small space which is occupied by a bubble of air at *a*. Invert over the whole a jar, *d*, and, placing the arrangement on the pump, exhaust. It will be found, as the exhaustion goes on, that the bubble *a* steadily increases in size until it fills all the bulb, and even the tube. On readmitting the pressure the bubble collapses to its original size. The air is, therefore, dilatable and condensible—that is, it is elastic.

If a bottle, the sides of which are square and the mouth hermetically closed, be placed beneath a receiver, and

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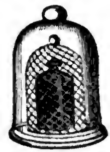
Why does sulphuric ether retain the liquid state? When the pressure is removed what becomes of the ether? What does experiment *Fig.* 28 prove?

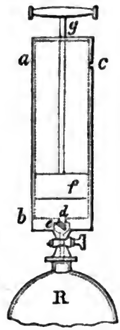
the pressure removed, the air imprisoned in the interior exerting its elastic force, will violently burst the bottle to pieces. It is, therefore, well to cover it with a wire cage, as represented in *Fig.* 29.

Fig. 29.



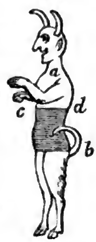
The elastic force of the air increases with its density. Powerful effects, therefore, arise by condensing air into a limited space. The condenser, which is an instrument for this purpose, is represented in *Fig.* 30. It consists of a tube, *a b*, in which there moves by a handle, *g*, a piston *f*. In one side of the tube, at *c*, there is an aperture, and at the lower part, *d*, there is a valve, *e*, opening downward. On pushing the piston down, the air beneath it is compressed, and, opening the valve *e*, by its elastic force, accumulates in the receiver, R. When the piston is pulled up a vacuum is made in the tube; but as soon as it passes the aperture, *c*, the air rushes in. Another downward movement drives this through the valve into the receiver, and the process may be continued until the elastic force of the included air becomes very great.

Fig. 30.



If the receiver be partly filled with water, and there be placed in it a piece of wax, an egg, or any yielding or brittle bodies, it will be found impossible to alter their figure by condensing the air to any extent whatever. And this arises from the circumstance already explained—that the pressure generated is equal in all directions.

Fig. 31.



The Cartesian image is a grotesque figure, made of glass, *Fig.* 31, hollow within and filled with water to the height *c d*. The upper part, *a*, is filled with air. The water is introduced through the tail, *b*, and the quantity of it is so adjusted that the figure just floats in water. If, therefore, it be placed in a deep

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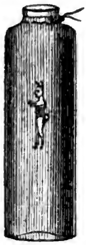
Under what circumstances may flat bottles be broken? What relation is there between elastic force and density? Describe the condenser. Why are not brittle bodies broken in such an instrument? What is the reason of the motions of the Cartesian images?

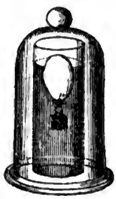
jar quite full of that liquid, and a cover of India-rubber or bladder tied on, as seen in *Fig*. 32, the figure floats up at the top; but by pressing with the finger on the cover, more water is forced into its interior, through the tail, *b*, and it descends to the bottom. On removing the finger the elastic force of the air, *a*, drives out this excess of water, and the image, becoming lighter, reascends. If the tail be turned on one side, as represented, the efflux of the water taking effect in a lateral direction, the figure spins round in its movements and performs grotesque evolutions.

Fig. 32.



On precisely the same principle, if a small bladder, only partly full of air, be sunk by a weight, *Fig*. 33, to the bottom of a deep glass of water, on covering the whole with a receiver and exhausting, the elastic force of the included air dilates the bladder, which rises to the top, carrying with it the weight. When the pressure is readmitted the bladder collapses and descends again to the bottom of the jar.

Fig. 33.



There are numerous machines in which the elastic force of air is brought into operation, such as the air-gun, blowing machines, &c. Indeed, the various applications of gunpowder itself depend on this principle—that material on ignition suddenly giving rise to the evolution of an immense quantity of gas, which exerts a great elastic force.

What is the cause of the ascent and descent of the little bladder, *Fig*. 33? On what do the air-gun and the action of gunpowder depend?

LECTURE VII.

PROPERTIES OF THE AIR.—*Marriotte's Law.—Proof for Compressions and Dilatations.—Case in which it Fails.—Resistance of the Air to Motion.—The Parachute.—The Air transmits Sound; supports Animal Life, Combustion, and Ignition.—Exists in the pores of some Bodies and is dissolved in others.*

ATMOSPHERIC air being thus a highly compressible and expansible substance, we have next to inquire what is the amount of its compressibility under different degrees of force? This has been determined experimentally by different philosophers, the true law having first been discovered by Boyle and Marriotte.

The density and elasticity of air are directly as the force of compression.

The volume which air occupies is inversely as the pressure upon it.

To illustrate, and at the same time to prove these laws, we make use of a tube, *a d c b*, so bent that it has two parallel branches, *a* and *b*. It is closed at *b*, and has a funnel-mouth at *a*. Sufficient mercury is poured into the tube to close the bend and to insulate a volume of air in *b d*. Of course this air exists under a pressure of one atmosphere equal to a column of mercury thirty inches long. Through the funnel, *a*, mercury is now to be poured; as it accumulates it presses upon the air in *d b*, and reduces its volume to *c*. If, in this manner, a column thirty inches long be introduced, it will be found that the air in *b d* is reduced to half. There are, therefore, now two atmospheres pressing on the included air—the atmosphere itself being one, and the thirty inches of mercury the other. Two atmospheres, therefore, reduce a given quantity of air into half its volume.

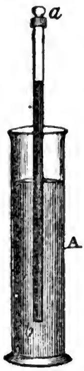
Fig. 34.

In the same manner it could be proved, if the tube

What is Marriotte's law? Describe Marriotte's instrument. What is its use? When the pressure on a gas is doubled, tripled, quadrupled, what volume does it assume?

were long enough, that the introduction of another thirty inches of mercury, giving a pressure of three atmospheres, would condense the air to one-third, that four would compress it to one-fourth, five to one-fifth, &c.

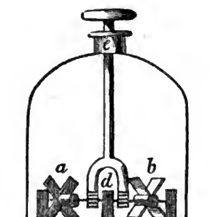
Fig. 35.



The truth of this law may be proved for rarefactions as well as condensations. For this purpose let there be taken a long tube, *a b*, *Fig.* 35, open at the end, *b*, and closed at *a*, with a screw; a jar, A, filled with mercury to a sufficient height, is also to be provided. Now let the screw at *a* be opened and the tube depressed in the mercury until the metal, by rising, leaves in the tube a few inches of air. The screw is now to be closed and the tube lifted. The included air at once dilates and a column of mercury is suspended. It will be found that when the air has dilated to double its volume, the length of the mercurial column in the tube will be fifteen inches—that is, half the barometric length.

By such experiments, it therefore appears that Marriotte's law holds both for condensations and rarefactions. This law has been verified until the air has been condensed twenty-seven times and rarefied one hundred and twelve times. In the case of gases, which easily assume the liquid form, it is, however departed from as that point is approached.

Fig. 36.



Besides the properties already described, atmospheric air possesses others which require notice. Among these may be mentioned its resistance to motion.

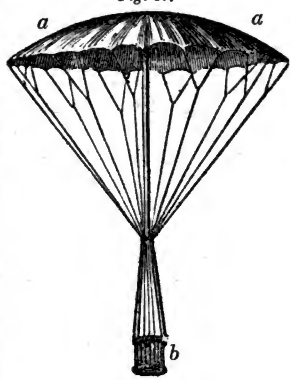
This property may be exhibited by means of the two wheels, *a b*, *Fig.* 36, which can be put in rapid rotatory motion by the rack, *d*, which moves up and down through an air-tight stuffing-box, *e*. The wheels are so arranged that the vanes of *a* move through the air edgewise, but

How may this be proved for rarefactions? To what extent has this law been verified? How may the resistance of the air be proved? In a vacuum is there any resistance?

those of *b* with their broad faces. On pushing down the rack, *d*, and making the wheels rotate with equal rapidity in the atmospheric air, one of them, *a*, will be found to continue its motion much longer than the other, *b:* and that this arises from the resistance which *b* experiences from the air is proved by making them rotate in the receiver from which the air has been exhausted, when *b* will continue its motion as long as *a*, both ceasing to revolve simultaneously.

The water-hammer affords another instance of the same principle. It consists of a tube a foot or more long and half an inch in diameter. In it there is included a small quantity of water, but no atmospheric air. When it is turned upside down the water drops from end to end, and emits a ringing, metallic sound. If there was any air in the tube, it would resist or break the fall of the water. A well-made mercurial thermometer exhibits the same fact. If there is a perfect vacuum in its tube, on turning the instrument upside down the metal drops like a hard, solid body against the closed end.

Fig. 37.



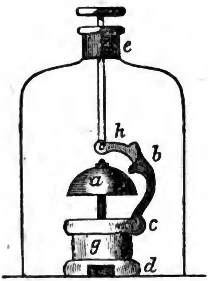
The Parachute is a machine by which aeronauts may descend from a balloon to the ground in safety. It bears a general resemblance to an umbrella, and consists of a strong but light surface, *a a*, *Fig.* 37, from which a car, *b*, is suspended. When it is detached from the balloon, it descends at first with an accelerated velocity, but this is soon checked by the resistance of the air, and the machine then falls at a rate nearly uniform, and very moderate.

In virtue of its elasticity, atmospheric air is the common medium for the transmission of sounds. Under the receiver of an air-pump let there be placed a bell, *a*, *Fig.* 38, the hammer, *b*, of which can be moved on its pivot, *c*, by means

Describe the parachute and its mode of action. How may it be proved that atmospheric air transmits sound?

of a lever, *h*, which is worked by a rod passing through the stuffing-box, *e*. The bell is placed on a leather drum, *g*, and fastened down to the pump-plate by means of a board, *d*. While the air is yet in the receiver, the sound is quite audible, but on exhausting it becomes fainter and fainter, and at last can no longer be heard. On readmitting the air the sound gradually increases, and at last acquires its original intensity. The leather cushion, *g*, is necessary to prevent the transmission of the sound through the solid part of the pump.

Fig. 38



The air also is absolutely necessary for the support of life. The higher warm-blooded animals die when the air is only partially rarefied. A rabbit, or other small animal, placed under an air-pump jar may remain there several minutes without being much disturbed; but if we commence withdrawing the air the animal instantly shows signs of distress, and if the experiment is continued, soon dies.

Fig. 39.

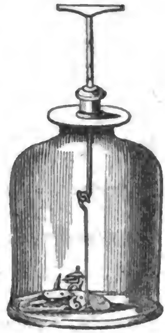
So, too, if a jar containing some small fishes be placed under an exhausted receiver, the animals either float on their backs at the surface of the water, or descend only by violent muscular exertions. Fishes respire the air which is dissolved in water, and hence it is somewhat remarkable that they continue to live for a considerable length of time in an exhausted receiver.

The air is also necessary to all processes of combustion. If a lighted candle be placed under a receiver, it will burn for a length of time; but if the air be withdrawn by the pump, it presently dies out. The smoke also descends to the bottom of the receiver, there being no air to buoy it up.

Why is it necessary that the bell should rest on a cushion? Prove that air is necessary for the support of life. Do fishes die at once in an exhausted receiver? Prove that the air is necessary to support combustion.

If a gun-lock be placed in an exhausted receiver, and the flint be made to strike, no sparks whatever appear; and, consequently, if there were powder in the pan, it could not be exploded. The production of sparks by the flint and steel is due to small portions of the latter which are struck off by the percussion burning in the air, and when the air is removed that combustion can, of course, no longer take place.

Fig. 40.



By taking advantage of the expansibility of the air, we are able to prove that it is included in the pores of many bodies. Thus, if an egg is dropped into a deep jar of water, and this covered with a receiver as soon as exhaustion is made, a multitude of air bubbles continually ascend through the water. Or if a glass of porter be placed beneath such a receiver, its surface is covered with a foam, the carbonic acid gas, which is the cause of its agreeable briskness, escaping away. And even common river or spring water treated in the same manner exhibits the escape of a considerable quantity of gas, which ascends through it in small bubbles, and gives it a sparkling appearance.

Fig. 41.

Fig. 42.

Why does a gun-lock fail to give sparks in vacuo? How may the presence of air in the pores of bodies be proved? Does water contain dissolved air?

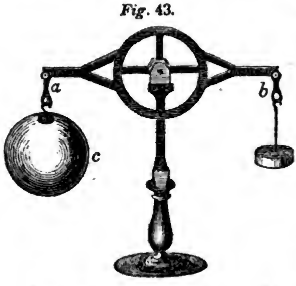
LECTURE VIII.

PROPERTIES OF THE AIR.—*Loss of Weight of Bodies in the Air.— Theory of Aerostation.— The Montgolfier Balloon.— The Hydrogen Balloon.—Mode of Controlling Ascent and Descent.—Artificial and Natural Currents in the Air.— Velocity with which Air flows into a Vacuum.— Velocity of Efflux of different Gases.—Principles of Gaseous Diffusion.— These Principles regulate the Constitution of the Atmosphere.*

ON principles which will be fully explained when we come to speak of specific gravity, it appears that a solid immersed in a fluid loses a portion of its weight. It follows, of course, that a substance weighs less in the air than it does in vacuo.

To one arm of a balance, *a*, *Fig.* 43, let there be hung a light glass globe, *c*, counterpoised in the air on the other arm, *b*, by means of a weight. If the apparatus be placed beneath a receiver, and the air exhausted, the globe *c*, descends, but on re-admitting the air the equilibrium is again restored. This instrument was formerly used for determining the density of the air.

Fig. 43.



A substance that has the same density as atmospheric air, when it is immersed in that medium, loses all its weight, and will remain suspended in it in any position in which it may be placed. But if it be lighter, it is pressed upward by the aerial particles, and rises upon the same principle that a cork ascends from the bottom of a bucket of water. And as the density of the air con-

What difference is there in the weight of a body in the air and in vacuo? What fact is illustrated by the instrument, *Fig.* 43? Under what circumstances does a substance in the air lose all its weight? On what principle do air balloons depend?

tinually diminishes as we go upward, it is evident that such a body, ascending from one stratum to another, will finally attain one having the same density as itself, and there it will remain suspended.

On these principles aerostation depends. Air balloons are machines which ascend through the atmosphere and float at a certain altitude. They are of two kinds: 1st, Montgolfier or rarefied air balloons; and, 2d, Hydrogen gas balloons.

The Montgolfier balloon, which was invented by the person whose name it bears, consists of a light bag of paper or cotton, which may be of a spherical or other shape; in its lower portion there is an aperture, with a basket suspended beneath for the purpose of containing burning material, as straw or shavings. On a small scale, a paper globe two or three feet in diameter, with a piece of sponge soaked in spirits of wine, answers very well. The hot air arising from the burning matter enters the aperture, distending the balloon, and makes it specifically lighter than the air, through which, of course, it will rise.

Fig. 44.

The hydrogen gas balloon consists, in like manner, of a thin, impervious bag, filled either with hydrogen or common coal gas. The former, as usually made, is from ten to thirteen times lighter than air; the latter is somewhat heavier. A balloon filled with either of these possesses, therefore, a great ascentional power, and will rise to considerable heights. Thus, Biot and Gay Lussac, in 1804, ascended in one of these machines to an elevation of 23,000 feet. When the balloon first ascends, it ought not to be full of gas, for as it reaches regions where the pressure is diminished, the gas within it is dilated, and though flaccid at first, it will become completely distended. If it were full at the time it left the ground, there would be risk of its bursting open as it arose. The gas balloon requires a valve placed at its top, so that gas may be

How many kinds of them are there? Describe the Montgolfier balloon. Describe the hydrogen balloon. What is the relative weight of hydrogen and air? Why must not the machine be full when it leaves the ground? How is it made to ascend and descend?

discharged at pleasure, and the machine made to descend. The aeronaut has control over its motions by taking up with him a quantity of sand in bags, as ballast. If he throws out sand the balloon rises, and if he opens the valve and lets the gas escape, it descends.

The rarefaction which air undergoes by heat makes it, of course, specifically lighter. Warm air, therefore, ascends, and cold air descends. When the door of a room which is very warm is open, the hot air flows out at the top, and the cold enters at the floor: these currents may be easily traced by holding a candle near the bottom and top of the door. In the former position the flame leans inward, in the latter it is turned outward, following the course of the draught.

The drawing of chimneys, and the action of furnaces and stoves depends on similar principles: the column of hot air contained in the flue ascending, and cold air replacing it below.

Similar movements take place in the open atmosphere. When the sun shines on the ground or the surface of the sea, the air in contact becomes warm, and rises; it is replaced by colder portions, and a continuous current is established. The direction of these currents is changed by a variety of circumstances, as the diurnal rotation of the earth and other causes less understood. On these depend the various currents known as Breezes, Trade-winds, Storms, Hurricanes.

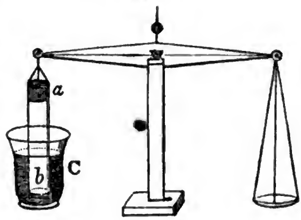
The atmosphere does not rush into a void space instantaneously, but, under common circumstances of density and pressure, with a velocity of about 1296 feet in one second. Its resisting action on projectiles moving through it with great velocities is intimately connected with this fact. A cannon-ball, moving through it with a speed of two or three thousand feet, leaves a total vacuum behind it, and condenses the air correspondingly in front. It is, therefore, subjected to a very powerful pressure continually tending to retard it. The rush of the air flowing into the vacuous spaces left by moving bodies is the cause of the loud explosions they make.

How does increase of heat affect the air? How may the currents in a warm room be traced? What is the principle on which furnaces and stoves depend? How do winds and currents in the air arise? What is the reason that a cannon-ball moving in the air has its velocity rapidly reduced?

When gases of different densities flow from apertures of the same size, the velocities with which they issue are different, and are inversely as the square roots of their densities. The lighter a gas is the greater is its issuing velocity; and therefore hydrogen, which is the lightest body, moves, under such circumstances, with the greatest speed.

The experiment represented in *Fig.* 45 illustrates these principles. Let there be a tube, *a b*, half an inch in diameter and six inches long, the end, *b*, being open and *a* closed with a plug of plaster of Paris, which is to be completely dried. Counterpoise this tube on the arm of a balance, and fill it with hydrogen gas, taking care to keep the plug dry, letting the open end, *b*, of the tube dip just beneath the surface of some water contained in a jar, C. In a very short time it will be discovered that the hydrogen is escaping through the plaster of Paris, and the tube, filling with water, begins to descend; and after a few minutes much of the gas will have gone out, and its place be occupied partly by atmospheric air, which comes in in the opposite direction, and partly by the water which has risen in the tube.

Fig. 45.



Even when gases are separated from each other by barriers, which, strictly speaking, are not porous, the same phenomenon takes place. Thus, if with the finger we spread a film of soap-water over the mouth of a bottle, *a*, and then expose it under a jar to some other gas, such as carbonic acid, this gas percolates rapidly through the film, and, accumulating in the bottle, distends the film into a bubble, as represented in *Fig.* 46. Meanwhile, a little atmospheric air escapes out of the bottle through the film in the opposite direction.

Fig. 46.

What is the law under which gases flow out of apertures? How may it be proved that gases can percolate through porous bodies, such as plugs of stucco? How may it be proved that they pass through films of water?

This propensity of gases to diffuse into each other is clearly shown by filling a bottle, H, *Fig.* 47, with a very light gas, as hydrogen; and a second one, C, with a heavy gas, as carbonic acid, and putting the bottles mouth to mouth. Diffusion takes place, the light gas descending and the heavy one rising until both are equally commixed. We see, therefore, that this property of gases is intimately concerned in determining the constitution of the atmosphere, which is made up of different substances, some of which are light and some heavy—the heavy ones not sinking, nor the light ones ascending, but both kept equally commixed by diffusion into each other.

Fig. 47.

Do the same phenomena ensue when no boundaries or barriers intervene? What have these principles to do with the constitution of the atmosphere?

PROPERTIES OF LIQUIDS.

HYDROSTATICS AND HYDRAULICS.

LECTURE IX.

PROPERTIES OF LIQUIDS.—*Extent and Depth of the Sea.—Its Influence on the Land.—Production of Fresh Waters.—Relation of Liquids and Gases.—Physical Condition of Liquids.—Different Degrees of Liquidity.—Florentine Experiment on the Compression of Water.—Oersted's Experiments.—Compressibility of other Liquids.*

HAVING disposed of the mechanical properties of atmospheric air, which is the type of gaseous bodies, in the next place we pass to the properties of water, which is the representative of the class of Liquids.

About two thirds of the surface of the earth are covered with a sheet of water, constituting the sea, the average depth of which is commonly estimated at about two miles. This, referred to our usual standards of comparison, impresses us at once with an idea of the great amount of water investing the globe; and, accordingly, imaginative writers continually refer to the ocean as an emblem of immensity.

But, referred to its own proper standard of comparison—the mass of the earth—it is presented to us under a very different aspect. The distance from the surface to the center of the earth is nearly four thousand miles. The depth of the ocean does not, therefore, exceed $\frac{1}{2000}$ part of this extent: and astronomers have justly stated, that were we on an ordinary artificial globe to place a

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What are the estimated dimensions of the sea? How do these compare with the size of the earth itself?

representation of the ocean, it would scarcely exceed in thickness the film of varnish already placed there by the manufacturer.

In this respect the sea constitutes a mere aqueous film on the face of the globe. Yet, insignificant as it is in reality, it has been one of the chief causes engaged in shaping the external surface, and also of modeling the interior to a certain depth—for geological investigations have proved the former action of the ocean on regions now far removed from its influence, in the interior of continents; and also its mechanical agency in the formation of the sedimentary or stratified rocks which are of enormous superficial extents and often situated at great depths.

Besides the salt waters of the sea, there are collections of fresh water, irregularly disposed, constituting the different lakes, rivers, &c. The direct sources of these are springs, which break forth from the ground, the little streams from which coalesce into larger ones. But the true source of all our terrestrial waters is the sea itself. By the shining of the sun upon it a portion is evaporated into the air, and this, carried away by winds and condensed again by cold, descends from the atmosphere as showers of rain, which, being received upon the ground, percolates until it is stopped by some less pervious stratum, and flowing along this at last breaks out wherever there is opportunity in the low grounds—thus constituting a spring. Such streamlets coalesce into rivers, which find their way back again to the sea, the point from which they originally came—an eternal round, which is repeated for centuries in succession.

From these more obvious phenomena of nature we discover a relationship between aerial and liquid bodies—the one passing without difficulty into the other form—and, indeed, many of the most important events around us depending on that fact. Experiment also shows that, in many instances, substances which under all common circumstances exist in the gaseous condition, can be made to assume the liquid. Thus, carbonic acid, which is one of the constitutents of the atmosphere, can by pressure be reduced to the liquid form, and can even be made to

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What great phenomena have arisen from the action of the sea? To what source are rivers and springs due? How is it they are formed? What relation is there between gases and liquids?

assume that of a solid. The main agents by which such transmutations are affected are cold and pressure.

The parts of liquids seem to have little cohesion. Viewing the forms of matter as being determined by the relation of those attractive and repulsive forces which are known to exist among particles, it is believed in that now under consideration—the liquid—that these forces are in equilibrio. For this reason, therefore, the particles of such bodies move freely among one another; and liquids, of themselves, cannot assume any determinate shape, but conform their figure to the vessels in which they are placed. Portions of the same liquid added to one another readily unite.

Among liquids we meet with what may be termed different degrees of liquidity. Thus the liquidity of molasses, oil, and water, is of different degrees. It seems as though there was a gradual passage from the solid to this state, a passage often exhibited by some of the most limpid substances. Thus alcohol, when submitted to an extreme degree of cold, assumes that partial consistency which is seen in melting beeswax, yet at common temperatures it is one of the most mobile bodies known. So, too, that compound of tin and lead which is used by plumbers as a solder, though perfectly fluid at a certain heat, passes, in the act of cooling, through various successive stages, and at a particular point becomes plastic and may be molded with a cloth.

If a quantity of atmospheric air is pressed upon by any suitable contrivance, it shrinks at once in volume. We have already proved this phenomenon and determined its laws. If water is submitted to the same trial, the result is very different—it refuses to yield: for this reason, inasmuch as the same fact applies to the whole class, liquids are spoken of as incompressible bodies.

It was at one time thought that the experiment of the Florentine academicians, who filled a gold globe with water, and on compressing it with a screw found the water ooze through the pores of the gold, proved completely the incompressibility of that liquid. But more recent ex-

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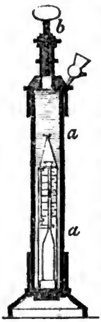
Do the parts of liquids cohere? What is the relation between their attractive and repulsive forces? Mention some of the distinctive qualities of liquids. Give examples of different degrees of liquidity. What experiment has been supposed to prove that water is incompressible?

periments have shown, beyond all doubt, that liquids are compressible, though in a less degree than gases. Thus, it is a common experiment to lower a glass bottle, filled with water and carefully stopped with a cork, into the sea.

Fig. 48.



On raising it again the cork is often found forced in, and the water is uniformly brackish. But in a more exact manner the fact can be proved, and even the amount of compressibility measured, by Œrsted's machine. This consists of a strong glass cylinder, *a a*, *Fig.* 48, filled with water, upon which pressure can be exerted by a piston driven by a screw, *b*. When the screw is turned and pressure on the liquid exerted, it contracts into less dimensions, but at the same time the glass, *a a*, yielding, distends, and the contraction of the water becomes complicated with the expansion of the glass in which it is placed.

To enable us to get rid of this difficulty, the instrument, *Fig.* 49, is immersed in the cylinder of water, as seen at *Fig.* 48. This consists of a glass reservoir, *e*, prolonged into a fine tube, *e f*, with a scale, *x*, attached to it. The reservoir and part of the tube are filled with water, and a little column of quicksilver, *x*, is upon the top of the water, serving to show its position. On one side there is a gage, *d*, partially filled with air. It serves to measure the pressure.

Fig. 49.

Now when the instrument, *Fig.* 49, is put in the cylinder in the position indicated in *Fig.* 48, and pressure made by the screw, *b*, it is clear that the water in the reservoir will be compressed, and the glass which contains it being pressed upon equally, internally and externally, will yield but very little. Making allowance, therefore, for the small amount of compression which the glass thus equally pressed upon undergoes, we may determine the compressibility of the water as the force upon it varies. It thus appears that water diminishes $\frac{1}{22000}$ part of its volume for each atmosphere of pressure upon it. In the same way the compressibility of alcohol has been determined to be $\frac{1}{11000}$.

Mention some that prove the contrary. Describe Œrsted's machine. What is the amount of the compressibility of water?

LECTURE X.

THE PRESSURES OF LIQUIDS.—*Divisions of Hydrodynamics.—Liquids seek their own Level.—Equality of pressures.—Case of different Liquids pressing against each other.—General Law of Hydrostatics.—Hydrostatic Paradox.—Law for Lateral Pressures.—Instantaneous communication of Pressure.—Bramah's Hydraulic Press.*

To the science which describes the mechanical properties of liquids the title of HYDRODYNAMICS is applied. It is divided into two branches, Hydrostatics and Hydraulics. The former considers the weight and pressure of liquids, the latter their motions in canals, pipes, &c.

A liquid mass exposed without any confinement to the action of gravity would spread itself into one continuous superficies, for all its parts gravitate independently of one another, each part pressing equally on all those around it, and being pressed on equally by them.

A liquid confined in a receptacle or vessel of any kind conforms itself to the solid walls by which it is surrounded, and its upper surface is perfectly plane, no part being higher than another. This level of surface takes place even when different vessels communicating with each other are used. Thus, if into a glass of water we dip a tube, the upper orifice of which is temporarily closed by the finger, but little water will enter, owing to the impenetrability of the air; but, as soon as the finger is removed, the liquid instantly rises, and finally settles at the same level inside of the tube that it occupies in the glass on the outside.

This result obviously depends on the equality of pressure just referred to, and it is perfectly independent of the form or nature of the vessel. If we take a tube bent

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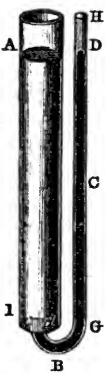
Into what branches is Hydrodynamics divided? Under the action of gravity what form does a free liquid assume? What is the effect when it is inclosed in a vessel? Give an illustration of the equality of pressure.

in the form of the letter U, and closing one of its branches with the finger, pour water into the other, as soon as the finger is removed the liquid rises in the empty branch, and, after a few oscillatory movements, stands at the same level in both.

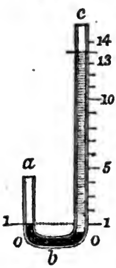
If one of the branches of such a tube is much wider than the other, the same result still ensues. Thus, as in *Fig.* 50, we might have a reservoir, A I, exposing an area of ten, or a hundred, or ten thousand times that of a tube rising from it, B G C H, but in the latter a liquid would rise no higher than in the former, both being at precisely the same level, A D. We perceive, therefore, from such an experiment, that the pressure of liquids does not depend on their absolute weight, but on their vertical altitude. The great mass of liquid contained in A exerts no more pressure on C than would a smaller mass contained in a tube of the same dimensions as C itself.

Fig. 50.



A variation of this experiment will throw much light upon the subject. Instead of using one, let there be two liquids, of which the specific gravities are different. Put one in one of the branches of the tube, *a b c*, *Fig.* 51, and the other in the other. Let the liquids be quicksilver and water. It will be found, under these circumstances, that the water does not press the quicksilver up to its own level, but that, for every thirteen and a half inches vertical height that it has in one of the branches the quicksilver has one inch in the other. Of course, as they communicate through the horizontal branch, *b*, the quicksilver must press against the water as strongly as the water presses against it; if it did not, movement would ensue. And such experiments, therefore, prove that it is the principle of equality of pressures which determines liquids to seek their own level.

Fig. 51.



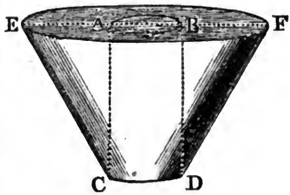
From this it therefore appears that a liquid in a vessel

Does this depend on the mass of a liquid? Prove that it depends on its height. What takes place when liquids of different densities are used? In what directions do liquids press?

not only exerts a pressure upon the bottom in the direction in which gravity acts, but also laterally and upward.

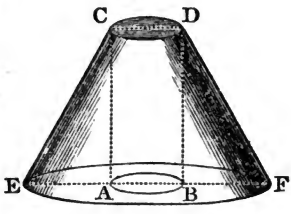
From what was proved by the experiment represented in *Fig.* 50, it follows that these pressures are by no means necessarily as the mass, but in proportion to the vertical height. If one hundred drops of water be arranged in a vertical line, the lowest one will exert on the surface on which it rests a pressure equal to the weight of the whole. And from such considerations we deduce the general rule for estimating the pressure a liquid exerts upon the base of a vessel. "Multiply the height of the fluid by the area of the base on which it rests, and the product gives a mass which presses with the same weight."

Fig. 52.



Thus in a conical vessel, E C D F, *Fig.* 52, the base, C D, sustains a pressure measured by the column A B C D. For all the rest of the liquid only presses on A B C D laterally, and resting on the sides E C and F D, cannot contribute any thing to the pressure on the base, C D

Fig. 53.



But in a conical vessel, E C D F, *Fig.* 53, the pressure on A B is measured by A B C D, as before; but the other portions of the liquid, not resting upon the sides, press also upon the bottom, E F, and the result, therefore, is the same as if the vessel were filled throughout to the height C A.

This law is nothing more than an expression of the fact that the actual pressure of a liquid is dependent on its vertical height and the area of its base. Its applications give rise to some singular results. Thus, the Hydrostatic bellows consists of a pair of boards, A, *Fig.* 54,

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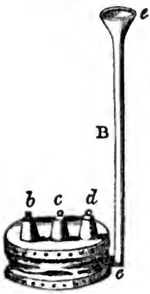
Give the rule for finding the pressure of a liquid on the base of the vessel containing it. Describe the hydrostatic bellows.

Fig. 54.



united together by leather, and from the lower one there rises a tube, *e* B *e*, ending in a funnel-shaped termination, *e*. If heavy weights, *b c d*, are put upon the upper board, or a man stands upon it, by pouring water down the tube the weight can be raised. It is immaterial how slender the tube, and, therefore, how small the quantity of water it contains, the total pressure resulting depends on the area of the bellows-boards, multiplied by the vertical height of the tube.

Theoretically, therefore, it appears that a quantity of water, however small, can be made to lift a weight however great—a principle sometimes spoken of as the HYDROSTATIC PARADOX.

But liquids exert a pressure against the sides as well as upon the bases of the containing vessel—the force of that pressure depending on the height. The law for estimating such pressure is, "The horizontal force exerted against all the sides of a vessel is found by multiplying the sum of the areas of all the sides into a height equal to half that at which the liquid stands."

When bodies are sunk in a liquid, the liquid exerts a pressure which depends conjointly on the surface of the solid and the depth to which its center is sunk. Thus, if into a deep vessel of water we plunge a bladder, to the neck of which a tube is tied, the bladder and part of the tube being filled with colored water, it will be seen, as the bladder is sunk, that the colored water rises in the tube.

A pressure exerted against one portion of a liquid is instantly communicated throughout the whole mass, each particle transmitting the same pressure to those around. A striking illustration of this is seen when a Prince Rupert's drop is broken in a glass of water, the glass being instantly burst to pieces.

Bramah's press, or the Hydrostatic press, is an illustration of the principle developed in this lecture—that every particle of a fluid transmits the pressure it receives, in all directions, to those around. It consists of a small

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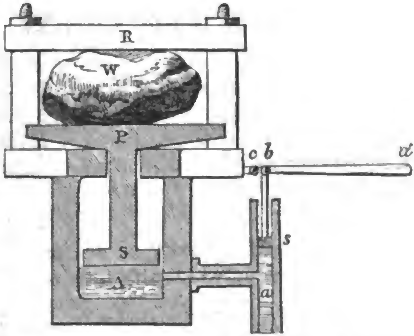
What is meant by the hydrostatic paradox? Give the rule for finding lateral pressures. Prove that a liquid exerts a pressure on bodies plunged in it. Give an illustration of the instantaneous communication of pressure.

metallic forcing-pump, *a*, *Fig.* 55, in which a piston, *s*, is worked by a lever, *c b d*. This little pump communicates with a strong cylindrical reservoir, A, in which a water-tight piston, S, moves, having a stout flat head, P, between which and a similar plate, R, supported in a frame, the substance to be compressed, W, is placed. The cylinder, A, and the

Fig. 55.



forcing-pump, with the tube communicating between them, are filled with water, the quantity of which can be increased by working the lever, *d*. Now it is obvious that any force, impressed upon the surface of the water in the small tube, *a*, will, upon the principles just described, be transmitted to that in A, and the piston, S, will be pushed up with a force which is proportional to its area, compared with that of the piston of the little cylinder, *a*. If its area is one thousand times that of the little one, it will rise with a force one thousand times as great as that with which the little one descends—the motive force applied at *d*, moreover, has the advantage of the leverage in proportion as *c d* is greater than *c b*. On these principles it may be shown that a man can, without difficulty, exert a compressing force of a million of pounds by the aid of such a machine of comparatively small dimensions.

Describe the hydraulic press.

LECTURE XI.

SPECIFIC GRAVITY.—*Definition of the term.—The Standards of Comparison.—Method for Solids.—Case when the Body is Lighter than Water.—Method for Liquids by the Thousand-Grain Bottle.—Effects of Temperature.—Standards of Temperature.—Other Methods for Liquids.—Method for Gases.—Effects of Temperature and Pressure.—The Hydrometer or Areometer.*

BY the specific gravity of bodies we mean the proportion subsisting between absolute weights of the same volume. Thus, if we take the same volume of water and copper, one cubic inch of each, for example, we shall find that the copper weighs 8·6 times as much as the water: and the same holds good for any other quantity, as ten cubic inches or one cubic foot. When of the same volume the copper is always 8·6 times the weight of the water.

Specific gravity is, therefore, a relative affair. We must have some substance with which others may be compared. The standard which has been selected for solids and liquids is water; that for gases and vapors, atmospheric air.

When we speak of the specific gravity of a substance which is of the liquid or solid kind, we mean to express its weight compared with the weight of an equal volume of water. Thus, the specific gravity of mercury is 13·5; that is to say, a given volume of it would weigh 13·5 times as much as an equal volume of water.

Apparently the simplest way for the determination of specific gravities of solids, would be to form samples of a uniform volume; as, for instance, one cubic inch. Their absolute weight, as determined by the balance, would be their specific gravities.

But in practice so many difficulties would be encountered in such a process that its results would be quite in-

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What is meant by specific gravity? What are the standards of comparison? Describe an apparently simple method of determining the specific gravity of solids.

exact; and the principles of hydrostatics furnish us with far more accurate means for resolving such problems.

To determine the specific gravity of a solid body, it is to be weighed first in air and then in water. In the latter instance it will weigh less than in the former, because it displaces a quantity of the water equal to its own volume, and this deficit in weight is the weight of the water so displaced. The weight in air and the loss in water being thus determined, to find the specific gravity, "Divide the weight in air by the loss in water, and the quotient is the specific gravity."

If the body be lighter than water, there must be affixed to it some substance sufficiently heavy to sink it, the weight of which, and also its loss of weight in water are previously known. Deduct this weight from the loss of the bodies when immersed together, and divide the absolute weight of the light body by the remainder; the quotient gives the specific gravity.

For the determination of the specific gravity of liquids several methods may be resorted to. One of the most simple is by the Thousand-grain Bottle. This consists of a light glass flask, *a*, *Fig.* 56, the stopper of which is also of glass with a fine perforation, *b*, through it. When the bottle is filled with distilled water, and the stopper inserted in its place, any excess of liquid is forced through the perforation, and the bottle, on being weighed, should be found to contain one thousand grains of the liquid exactly.

Fig. 56.

If any other liquid be in like manner placed in this bottle, by merely ascertaining its weight we at once determine its specific gravity. Thus, if it be filled with oil of vitrol or muriatic acid, it will be found to hold 1845 grains of the former and 1210 of the latter. Those numbers, therefore, represent the specific gravities of the bodies respectively.

This instrument enables us to illustrate, in a very satisfactory manner, the effect of temperature on specific grav-

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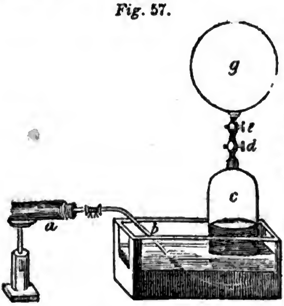
Give the general hydrostatic method. What is done when the body is lighter than water? Give the method in the case of liquids by the Thousand-grain Bottle.

ity. It has been said that the Thousand-grain bottle is so called from its containing precisely one thousand grains of water; but very superficial consideration satisfies us that this can only be the case at a particular temperature. Suppose the bottle is of such dimensions that at 60° Fahrenheit it contains exactly one thousand grains, if we raise its temperature to 70° Fahrenheit, the water will expand, or if we lower it to 50° Fahrenheit it will contract exactly as if it were a liquid in a thermometer. It is, therefore, very clear that temperature must always enter into these considerations, and that before we can express the relation of weight between any substance, whether solid or liquid, and that of an equal volume of water, we must specify at what particular temperature the experiment was made. For many purposes 60° Fahrenheit is selected, and for others $39\frac{1}{2}$° Fahrenheit, which is the temperature of the maximum density of water.

There is a second method by which the specific gravity of fluids may be known. It is to weigh a given solid (as a mass of glass) in the fluids to be tried, and determine the loss of weight in each case. Inasmuch as the solid displaces its own volume of the different liquids, the losses it experiences when thus weighed will be proportional to the specific gravities. The following rule, therefore, applies: "Divide the loss of weight in the different liquids by the loss of weight in water, and the quotients will give the specific gravities of the liquids under trial."

Fig. 57.



For the determination of the specific gravities of gases a plan analogous in principle to that of the Thousand-grain bottle is resorted to. A light glass flask, *g*, exhausted of air, is attached by means of the stop-cocks, *e d*, to the jar, *c*, containing the gas to be tried. This gas has been passed through a drying-tube, *a*, by means of a bent pipe, *b*, into the jar, *c*, over mercury. On

Describe the effects of temperature on specific gravity. Give another method for determining the density of liquids. How is that of gases discovered?

opening the stop-cock the gas flows into *g*, and its weight may then be determined by the balance.

From the greater dilatation of gases by heat, all that has been just said in relation to the effect of temperature on specific gravity applies here still more strongly. It is to be recollected that this form of bodies is compared with atmospheric air taken as the standard.

For gases another disturbing agency beside temperature intervenes—it is pressure. Atmospheric pressure is incessantly varying, and the densities of gases vary with it. It is not alone the thermometer, but also the Barometer which must be consulted, and the temperature and pressure both specified. Besides, great care must be taken in transferring the gas from the jars in which it is contained, that it is not subjected to any accidental pressures in the apparatus itself, and that the flask in which it is weighed is not touched by the hands or submitted to any other warming or cooling influences.

For the determination of the densities of liquids there is still another method, often more convenient than the former, and very commonly resorted to, it is by the aid of instruments which pass under the name of Hydrometers or Areometers.

The principle on which these act is, that when a body floats upon water, the quantity of fluid displaced is equal *in volume* to the volume of the part of the body immersed, and *in weight* to the weight of the whole body.

Thus, a piece of cork floating on the surface of quicksilver, water, and alcohol, sinks in them to very different depths: in the quicksilver but little, in the water more, and in the alcohol still deeper; but in every instance the weight of the quantity of the liquid displaced is equal to that of the cork.

It is plain, therefore, that to determine the specific gravity of a liquid, we have only to determine the depth to which a floating body will be immersed in it. The hydrometer fulfills these conditions. It consists of a cylindrical cavity of glass, A, *Fig.* 58, on the lower part of which a spherical bulb, B, is blown, the latter being filled with a suitable quantity of small shot or quicksil-

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What disturbing effects are encountered in the case of gases? On what principle is the hydrometer constructed.

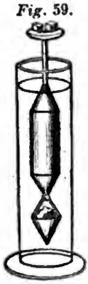
ver. From the cylindrical portion, A, a tube, C, rises, in the interior of which is a paper scale bearing the divisions.

Fig. 58

The whole weight of the instrument is such that it floats in the liquid to be tried, and if that liquid is to be compared with water, and is lighter than water, the zero of the divided scale is toward the lower end of the paper; but if the liquid be heavier than water, the zero is toward the top of the scale. Tables are usually constructed so that, by their aid, when the point at which the hydrometer floats in a given liquid is determined in any experiment, the specific gravity is expressed opposite that number in the table.

Of these scale-hydrometers we have several different kinds, according as they are to determine different liquids. Among them may be mentioned Beaume's hydrometer, an instrument of constant use in chemistry. In the finer kinds of areometers the weighted sphere, B, *Fig.* 58, forms the bulb of a delicate thermometer, the stem of which rises into the cavity, A. This enables us to determine the temperature of the liquid at the same time with its specific gravity.

Fig. 59.



Nicholson's gravimeter is a hydrometer which enables us to determine the density either of solids or liquids. It is represented at *Fig.* 59.

Describe the hydrometer.

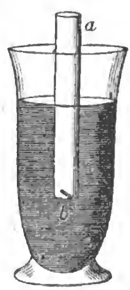
LECTURE XII.

HYDROSTATIC PRESSURES AND FORMATION OF FOUNTAINS. — *Fundamental Fact of Hydrostatics — holds also for Gases.—Illustrations of Upward Pressure.—Determination of Specific Gravities of Liquids on these Principles.—Theory of Fountains.—Cause of Natural Springs.—Artesian Wells.*

THE fundamental fact in hydrostatics thus appears to be, that as each atom of a liquid yields to the influence of gravity without being restrained by any cohesive force, all the particles of such a mass must press upon those which are immediately beneath them, and therefore the pressure of a liquid must be as its depth.

The same fact has already been recognized for elastic fluids, in speaking of the mechanical properties of the earth's atmosphere, which, for this very reason, and also from the circumstance that it is a highly compressible body, possesses different densities at different heights. The lower regions have to sustain or bear up the weight of all above them, but as we go higher and higher this weight becomes less and less, until at the surface it ceases to exist at all.

Fig. 60.



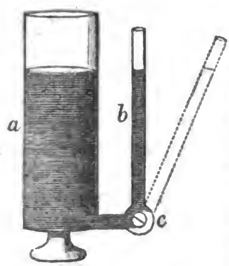
We have already shown from the nature of a fluid such pressures are propagated equally in all directions, upward and laterally, as well as downward. This important principle deserves, however, a still further illustration from the consequences we have now to draw from it. Let a tube of glass, *a b*, *Fig.* 60, have its lower end, *b*, closed with a valve slightly weighted and opening upward, the end, *a*, being open. On holding the tube in a vertical position, the valve is kept shut by its own weight. But if we depress it in

What is the fundamental fact in hydrostatics? Does this hold for elastic fluids? Describe the illustration represented in *Fig.* 60. How may it be made to prove the downward pressure of water?

a vessel of water, as soon as a certain depth is reached the *upward* pressure of the water forces the valve, and the tube begins to fill. Still further, if before immersing the tube we fill it to the height of a few inches with water, we shall find that it must now be depressed to a greater depth than before, because the downward pressure of the included water tends to keep the valve shut.

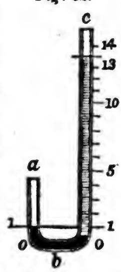
From the same principles it follows, that whenever a liquid has freedom of motion, it will tend to arrange itself so that all parts of its surface shall be equidistant from the center of the earth. For this reason the surface of water in basins and other reservoirs of limited extent is always in a horizontal plane; but when those surfaces are of greater extent, as in the case of lakes and the sea, they necessarily exhibit a rounded form, conforming to the figure of the earth. It is also to be remembered that, when liquids are included in narrow tubes, the phenomena of capillary attraction disturb both their level and surface-figure.

Fig. 61.



All liquids, therefore, tend to find their own level. This fact is well illustrated by the instrument, *Fig.* 61, consisting of a cylinder of glass, *a*, connected by means of a horizontal branch with the tube, *b*, which moves on a tight joint at, *c*. By this joint, *b* can be set parallel to *a*, or in any other position. If *a* is filled with water to a given height, the liquid immediately flows through the horizontal connecting pipe, and rises to the same height in *b* that it occupies in *a*. Nor does it matter whether *b* be parallel to *a*, or set at any inclined position, the liquid spontaneously adjusts itself to an equal altitude.

Fig. 62.

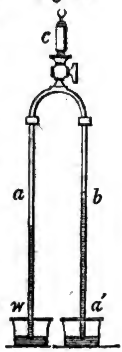


The same liquid always occupies the same level. But when in the branches of a tube we have liquids, the specific gravities of which are different, then, as has already been stated in Lecture

What is the surface-figure of liquids? Describe the illustration given in *Fig.* 61. What is the law of different liquids pressing on each other in a tube?

X., they rise to different heights. The law which determines this is, "*The heights of different fluids are inversely as their specific gravities.*" If, therefore, in one of the branches of a tube, *a b*, *Fig.* 62, some quicksilver is poured so as to rise to a height of one inch, it will require in the other tube, *b c*, a column of water 13½ inches long to equilibrate it, because the specific gravities of quicksilver and water are as 13½ to 1.

Fig. 63.



A very neat instrument for illustrating these facts is shown in *Fig.* 63. It consists of two long glass tubes, *a b*, which are connected with a small exhausting-syringe, *c*, their lower ends being open dip into the cups, *w á*, in which the liquids whose specific gravities are to be tried are placed. Let us suppose they are water and alcohol. The syringe produces the same degree of partial exhaustion in both the tubes, and the two liquids equally pressed up by the atmospheric air, begin to rise. But it will be found that the alcohol rises much higher than the water—to a height which is inversely proportional to its specific gravity.

Fig. 64.

When in the instrument, *Fig.* 61, we bend the tube, *b*, upon its joint, so that its end is below the water-level in *a*, the liquid now begins to spout out: or if, instead of the jointed tube, we have a short tube, C *e* D, *Fig.* 64, proceeding from the reservoir, A B, the water spouts from its termination and forms a fountain, E F, which rises nearly to the same height as the water-level. The resistance of the air and the descent of the falling drops shorten the altitude, to which the jet rises to a certain extent. On the top of the fountain a cork ball, G, may be s spended by the playing water.

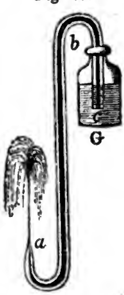
The same instrument may be used to show the equality of the vertical and lateral pressures at any point. For let the tube, D E, be removed so

At what heights will quicksilver and water stand? Describe the instrument, *Fig.* 63. What fact does it show? Under what circumstances does a liquid spout? How may a fountain be formed?

as to leave a circular aperture at *e;* also let C be a plug closing an aperture in the bottom of exactly the same size as *e*. Now if the reservoir, A B, be filled to the height *g*, and kept at that point by continually pouring in water, and the quantities of liquid flowing out through the lateral aperture, *e*, and the vertical one, C, be measured, they will be found precisely the same, showing, therefore, the equality of the pressures; but if an aperture of the same size were made at *f*, the quantity would be found correspondingly less.

It is upon these principles that fountains often depend. The water in a reservoir at a distance is brought by pipes to the jet of the fountain, and there suffered to escape. The vertical height to which it can be thrown is as the height of the reservoir, and by having several jets variously arranged in respect of one another, the fountain can be made to give rise to different fanciful forms, as is the case with the public fountains in the city of New York.

Fig. 65.



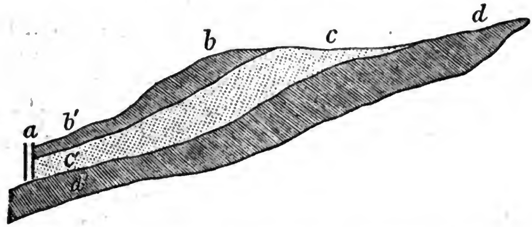
A simple method of exhibiting the fountain is shown in *Fig*. 65. A jar, G, is filled with water, and a tube, bent as at *a b c*, is dipped in it. By sucking with the mouth at *a*, the water may be made to fill the tube, and then, on being left to itself, will play as a fountain.

On similar principles we account for the occurrence of springs, natural fountains, and Artesian wells. The strata composing the crust of the earth are, in most cases, in positions inclined to the horizon. They also differ very greatly from one another in permeability to water—sandy and loamy strata readily allowing it to percolate through them, while its passage is more perfectly resisted by tenacious clays. On the side of a hill, the superficial strata of which are pervious, but which rest on an impervious bed below, the rain water penetrates, and being guided along the inclination, bursts out on the sides of the hill or in the valley below, wherever there is a weak place or where its vertical pressure has become sufficiently powerful to force a way. This constitutes a common spring.

Prove the equality of vertical and lateral pressures by the instrument, *Fig*. 64. What is the principle of fountains? Describe the apparatus, *Fig*. 65. On what principle do springs flow from the ground?

The general principle of the Artesian or overflowing wells is illustrated in *Fig.* 66. Let *b′ b c d*, be the surface of a region of country the strata of which, *b b′* and

Fig 66.



d d′, are more or less impervious to water, while the intermediate one, *c c′*, of a sandy or porous constitution, allows it a freer passage. When in the distant sandy country at *c*, the rain falls, it percolates readily and is guided by the resisting stratum, *d d′*. Now if at *a*, a boring is made deep enough to strike into *c c′* or near to *d′* on the principles which we have been explaining, the water will tend to rise in that boring to its proper hydrostatic level, and therefore, in many instances, will overflow at its mouth. The region of country in which this water originally fell may have been many miles distant.

It follows, from the action of gravity on liquids, that if we have several which differ in specific gravity in the same vessel, they will arrange themselves according to their densities. Thus, if into a deep jar we pour quicksilver, solution of sulphate of copper, water, and alcohol, they will arrange themselves in the order in which they have been named.

What are Artesian wells? When several liquids are in the same vessel, how do they arrange themselves?

LECTURE XIII.

Of Flowing Liquids and Hydraulic Machines.—*Laws of the Flowing of Liquids.—Determination of the Quantity Discharged.—Contracted Vein.—Parabolic Jets.—Relative Velocity of the Parts of Streams.—Undershot, Overshot, Breast-Wheels.—Common Pump.—Forcing-Pump.—Vera's Pump.—Chain-Pump.*

If a liquid, the particles of which have no cohesion, flows from an aperture in the bottom of its containing vessel, the particles so descending fall to the aperture with a velocity proportional to the height of the liquid.

The force and velocity with which a liquid issues depend, therefore, on the height of its level—the higher the level the greater the velocity.

As the pressures are equal in all directions, and as it is gravity which is the cause of the flow, "The velocity which the particles of a fluid acquire when issuing from an orifice, whether sideways, upward, or downward, is equal to that which they would have acquired in falling perpendicularly from the level of the fluid to that of the orifice."

When a liquid flows from a reservoir which is not replenished, but the level of which continually descends, the velocity is uniformly retarded: so that an unreplenished reservoir empties itself through a given aperture in twice the time which would have been required for the same quantity of water to have flowed through the same aperture, had the level been continually kept up to the same point.

The theoretical law for determining the quantity of water discharged from an orifice, and which is, that "*the quantity discharged in each second may be obtained by multiplying the velocity by the area of the aperture,*" is not found to hold good in practice—a disturbance arising from the adhesion of the particles to one another, from their

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On what does the velocity of a flowing liquid depend? What is that velocity equal to? What is the difference of flow between a replenished and an unreplenished reservoir? Why does not the theoretical law for the discharge of water hold good?

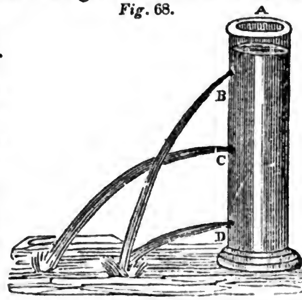
friction against the aperture, and from the formation of what is designated "the contracted vein." For when water flows through a circular aperture in a plate, the diameter of the issuing stream is contracted and reaches its minimum dimensions at a distance about equal to that of half the diameter of the aperture, as at *s s'*, *Fig.* 67. This effect arises from the circumstance that the flowing water is not alone that which is situated perpendicularly above the orifice, but the lateral portions likewise move. These, therefore, going in oblique directions, make the stream depart from the cylindrical form, and contract it, as has been described.

Fig. 67.

By the attachment of tubes of suitable shapes to the aperture, this effect may be avoided, and the quantity of flowing water very greatly increased. A simple aperture and such a tube being compared together, the latter was found to discharge half as much more water in the same space of time.

As the motion of flowing liquids depends on the same laws as that of falling solids, and is determined by gravity, it is obvious that the path of a spouting jet, the direction of which is parallel or oblique to the horizon, will be a parabola; for, as we shall hereafter see, that is the path of a body projected under the influence of gravity in vacuo. When a liquid is suffered to escape in a horizontal direction through the side of a vessel, it may be easily shown to flow in a parabolic path, as in *Fig.* 68. The maximum distance to which a jet can reach on a horizontal plane is, when the opening is half the height of the liquid, as at C, and at points B and D equidistant from C, it spouts to equal distances.

Fig. 68.



To measure the velocity of flowing water, floating bodies are used: they drift, immersed in the stream under examination. A bottle

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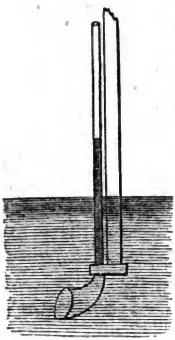
What is meant by the "contracted vein?" From what does this arise? How may the quantity of flowing water be increased? What is the path of a spouting jet?

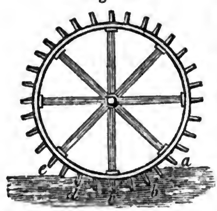
partly filled with water, so that it will sink to its neck, with a small flag projecting, answers very well; or the number of revolutions of a wheel accommodated with float-boards may be counted.

Fig. 69.



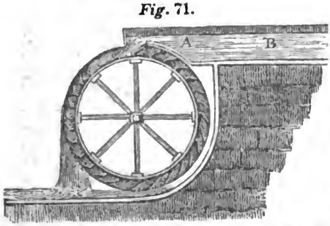
In any stream the velocity is greatest in the middle (where the water is deepest), and at a certain distance from the surface. From this point it diminishes toward the banks. Investigations of this kind are best made by Pictot's stream-measurer, *Fig.* 69. It consists of a vertical tube with a trumpet-shaped extremity, bent at a right angle. When plunged in motionless water the level in the tube corresponds with that outside, but the impulse of a stream causes the water to rise in the tube until its vertical pressure counterpoises the force.

Fig. 70.



The force of flowing water is often employed for various purposes in the arts. We have several different kinds of water-wheels, as the undershot, the overshot, and the breast-wheel. The first of these consists of a wheel or drum revolving upon an axis, and on the periphery there are placed float-boards, *a b c d*, &c. It is to be fixed so that its lower floats are immersed in a running stream or tide, and is driven round by the momentum of the current.

Fig. 71.



The overshot-wheel, in like manner, consists of a cylinder or drum, with a series of cells or buckets, so arranged that the water which is delivered by a trough, A B, on the uppermost part of the wheel, may be held by the descending buckets as long as possible. It is the weight

How may the velocity of flowing water be measured? Describe the stream-measurer. What is the undershot-wheel? What is the overshot-wheel?

of this water that gives motion to the wheel on its axis.

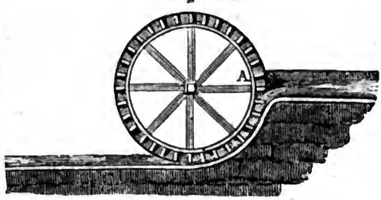
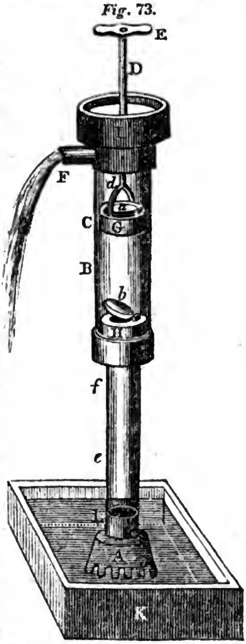


Fig. 72.

The breast-wheel, in like manner, consists of a drum working on an axis, and having float-boards on its periphery. It is placed against a wall of a circular form, and the water brought to it fills the buckets at the point A, and turns the wheel, partly by its momentum and partly by its weight.

Of these three forms the overshot-wheel is the most powerful.

Fig. 73.



There are a great many contrivances for the purpose of raising water to a higher level. These constitute the different varieties of pumps.

The common pump is represented in *Fig*. 73. It consists of three parts: the suction-pipe, the barrel, and the piston. The suction-pipe, *f e*, is of sufficient length to reach down to the water, A, proposed to be raised from the reservoir, L. The barrel, C B, is a perfectly cylindrical cavity, in which the piston, G, moves, air-tight, up and down, by the rod, *d*. It is commonly moved by a lever, but in the figure a rod and handle, D E, are represented. On one side is the spout, F. At the top of the suction-pipe, at H, there is a valve, *b*, and also one on the piston, at *a*. They both open upward. When the piston is raised from the bottom of the barrel and again depressed, it exhausts the air in

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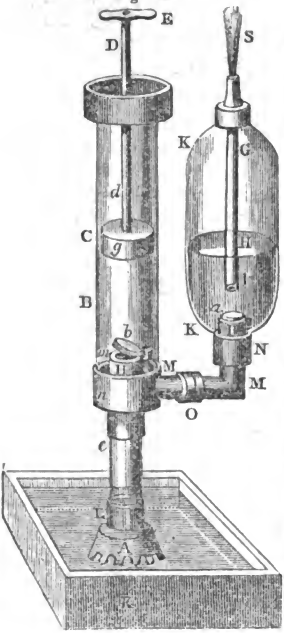
What is the breast-wheel? Which of these is the most powerful? Describe the lifting-pump.

the suction-pipe, and the water rises from the reservoir, pressed up by the atmosphere. After a few movements of the piston the barrel becomes full of water, which, at each successive lift, is thrown out of the spout, F. The action of this machine is readily understood, after what has been said of the air-pump, which it closely resembles in structure.

Fig. 74.



In the forcing-pump the suction pipe, *e* L, is commonly short, and the piston, *g*, has no valve. On the box at H, there is a valve, *b*, as in the former machine, and when the piston is moved upward in the barrel, C B, by the handle, E, and rod, D *d*, the water, A, rises from the reservoir, L, and enters the barrel. During the downward movement of the piston the valve, *b*, shuts, and the water passes by a channel round *m*, through the lateral pipe, M O M N, into the air vessel, K K. The entrance to this air-vessel at P, is closed by a valve, *a*, and there proceeds from it a vertical tube, H G, open at both ends. After a few movements of the piston, the lower end, I, of this tube becomes covered with water, and any further quantity now thrown in compresses the air in the space, H G, which, exerting its elastic force, drives out the water in a continuous jet, S. The reciprocating motion of the piston may, therefore, be made to give rise to a continuous and unintermitting stream by the aid of the air-vessel, K K.

Among other hydraulic machines may be mentioned Vera's pump, more, however, from its peculiar construction than for any real value it possesses. It consists of a

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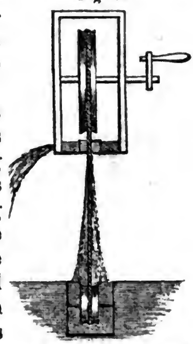
Describe the forcing-pump.

pair of pulleys, over which a rope is made to run rapidly, the lower one is immersed in the water to be raised. By adhesion a portion of the water follows the rope in its movements, and is discharged into a receptacle placed above.

Fig. 75.



The chain-pump consists of a series of flat plates held together by pieces of metal, so arranged that, by turning an upper wheel, the whole chain is made to revolve, on one side ascending and on the other descending. As the flat plates pass upward they move through a trunk of suitable shape, and therefore continually lift in it a column of water. The chain-pump requires deep water to work in, and cannot completely empty its reservoir, but it has the advantage of not being liable to be choked.

LECTURE XIV.

HYDRAULIC MACHINES.—THEORY OF FLOTATION.—*Archimedes' Screw.—The Syphon acts by the Pressure of Air.—The Descent, Ascent, and Flotation of Solids in Liquids.—Quantity of Water displaced by a Floating Solid.—Case where fluids of different densities are used.—Equilibrium of Floating Solids.*

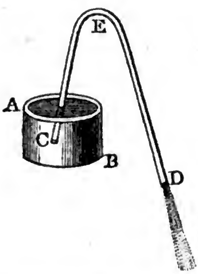
THE screw of Archimedes is an ancient contrivance, invented by the philosopher whose name it bears, for the purpose of raising water in Egypt. It consists of a hollow screw-thread wound round an axis, upon which it can be worked by means of a handle. The lower end of this spiral tube dips in the reservoir from which the water is to be raised, and by turning the handle the water continually ascends the spire and flows out at its upper extremity.

The syphon is a tube with two branches, C E, D E,

What is Vera's pump? Describe the chain-pump. Describe the screw of Archimedes. What is a syphon?

Fig. 76, of unequal length, often employed in the arts for the purpose of raising or decanting liquids. The method of using it is first to fill it, and then placing the shorter branch in the vessel, B, to be decanted, the liquid ascends to the bend and runs down the longer branch. It is obvious that this motion arises from the inequality of weight of the columns in the two branches. The long column overbalances the short one, and determines the flow; but this cannot take place without fresh quantities rising through the short branch, impelled by the pressure of the air. The syphon, therefore, is kept full by the pressure of the air, and kept running by the inequality of the lengths of the columns in its branches.

Fig. 76



This inequality is not to be measured by the actual lengths of the glass branches themselves, but it is to be estimated by the difference of level, A, of the liquid in the vessel to be decanted and the free end, D, of the Syphon.

That this instrument acts in consequence of the pressure of the air is shown by making a small one discharge quicksilver under an air-pump receiver. Its action will cease as soon as the air is removed.

By the aid of a syphon liquids of different specific gravities may be drawn out of a reservoir without disturbing one another, and those that are in the lower part without first removing those above. Upon the same principle water may also be conducted in pipes over elevated grounds.

Of the Floating of Bodies in Liquids.

A solid substance will remain motionless in the interior of a liquid mass when it is of the same specific gravity. Under these circumstances the forces which tend to make it sink are its own weight and the weight of the column

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Why does water ascend in its short branch? Why does it run from the longer? How is the inequality of the branches measured? How can it be proved that its action depends on the pressure of the air? What are the uses of the syphon? Under what circumstances will a solid remain motionless in a liquid?

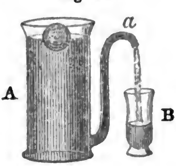
of water which is above it. But as its weight is the same as that of an equal volume of the liquid in which it is immersed, this downward tendency is counteracted and precisely equilibrated by the upward pressure of the surrounding liquid. Consequently the solid remains motionless in any position, precisely as a similar mass of the liquid itself would be.

But if the density of the immersed body is greater than that of an equal bulk of the liquid, then the downward forces preponderate over the upward pressure, and the solid descends.

If, on the other hand, the solid is lighter than an equal volume of the liquid, the upward pressure of the surrounding liquid overcomes the downward tendency, and the body rises to the surface and floats.

In the act of floating, the body is divided into two regions: one is immersed in the liquid and the rest is in the air. The part which is immersed under the surface of the liquid is *such as displaces a quantity of that liquid as is precisely equal in weight to the floating solid.* This may be proved experimentally. Fill a glass, A, with water until it runs off through the spout, *a*, then immerse in it a floating body, such as a wooden ball; the ball will displace a quantity of water, which, if it be collected in the receiver, B, and weighed, will be found precisely equal to the weight of the wood.

Fig. 77.



In any fluid a solid body will therefore sink to a depth which is greater as its specific gravity more nearly approaches that of the liquid. As soon as the two are equal the solid becomes wholly immersed.

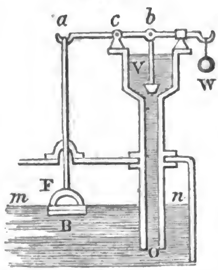
In fluids of different densities any floating body sinks deeper in that which has the smallest density. It will be recollected that these are the principles which are involved in the action of hydrometers. They are also applied in the case of specific-gravity bulbs, which are small glass bulbs, with solid handles, adjusted by the

Under what will it rise, and under what will it sink? What portion of the floating body is immersed? How may this be proved? How do the specific gravities of the solid and the liquid on which it floats affect the phenomenon?

maker, so as to be of different densities. When a number of these are put into a liquid some will float and some will sink; but the one which remains suspended, neither floating nor sinking, has the same specific gravity as the liquid. That specific gravity is determined by the mark engraved on the bulb.

When a body floats on the surface of water it tends to take a position of stable equilibrium. The principles brought in operation here will be more fully described when we come to the study of the center of gravity of bodies. For the present, it is sufficient to state that stable equilibrium ensues when the center of gravity of the floating solid is in the same vertical line as the center of gravity of the portion of fluid displaced, and as respects position beneath it. These considerations are of great importance in the art of ship-building, and also in the right distribution of the cargo or ballast of a ship.

Fig. 78.



The principle of flotation is ingeniously applied in the ball-cock, an instrument for keeping cisterns or boilers filled with a regulated amount of water. Thus, suppose that *m n*, *Fig.* 78, be the level of the water in the boiler of a steam-engine; on its surface let there float a body, B, attached by means of a rod, F *a*, to a lever, *a c b*, which works on the fulcrum *c;* on the other side of the lever, at *b*, let there be attached, by the rod *b* V, a valve, V, allowing water to flow into the boiler, through the feed-pipe, V O. Now, as the level of the water, *m n*, in the boiler lowers through evaporation, the float, B, sinks with it, and depresses the end, *a*, of the lever; but the end, *b*, rising, lifts the valve, V, and allows the water to go down the feed-pipe; and as the level again rises in the boiler the valve, V, again shuts. Instead of a piece of wood or hollow copper ball, a flat piece of stone, B, is commonly used; and to make it float it is counterpoised by a weight, W, on the opposite arm of the lever.

How are specific-gravity bulbs used? What is the position of stable equilibrium in a floating body? Describe the construction and action of the ball-cock.

OF REST AND MOTION.

MECHANICS.

LECTURE XV.

MOTION AND REST.—*Causes of Motion.—Classification of Forces.—Estimate of Forces.—Direction and Intensity.—Uniform and Variable Motions.—Initial and Final Velocities.—Direct, Rotatory, and Vibratory Motions.*

ALL objects around us are necessarily in a condition either of motion or of rest. We shall soon find that matter has not of itself a predisposition for one or other of these states; and it is the business of natural philosophy to assign the particular causes which determine it to either in any special instance. A very superficial investigation soon puts us on our guard against deception. Things may appear in motion which are at rest, or at rest when in reality they are in motion. A passenger in a railroad car sees the houses and trees in rapid motion, though he is well assured that this is a deception—a deception like that which occurs on a greater scale in the apparent revolution of the stars from east to west every night—the true motion not being in them, but in the earth, which is turning in the opposite direction on its axis.

If deceptions thus take place as respects the state of motion, the same holds good as respects the state of rest. On the surface of the earth even those objects which seem to us to be quite stationary are not so in reality. Natural objects, as mountains and the various works of man, though they seem to maintain an unchangeable relation as respects position with all the world for centuries together, are but in a condition of RELATIVE REST. They are, of

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What two states do bodies assume? What deceptions may occur in relation to motion and rest? What is meant by relative and what by absolute rest?

course, affected by the daily revolution of the earth on its axis, and accompany it in its annual movements round the sun. Indeed, as respects themselves, their parts are continually changing position. Whatever has been affected by the warmth of summer shrinks into smaller space through the cold of winter. Two objects which maintain their position toward each other are said to be at *relative rest;* but we make a wide distinction between this and *absolute rest.* All philosophy leads us to suppose that throughout the universe there is not a solitary particle which is in reality in the latter state.

Whenever an object, from a state of apparent rest, commences to move, a cause for the motion may always be assigned. And inasmuch as such causes are of different kinds, they may be classified as primary or secondary motive powers. The primary motive powers are universal in their action. Such, for instance, as the general attractive force of matter or GRAVITY. The secondary are transient in their effects. The action of animals, of elastic springs, of gunpowder, are examples. Of the secondary forces, some are momentary and others more permanent, some giving rise to a blow or shock, and some to effects of a continued duration.

Forces may be compared together as respects their intensities by numbers or by lines. Thus one force may be five, ten, or a hundred times the intensity of another, and that relation be expressed by the appropriate figures. In the same manner, by lines drawn of appropriate length, we may exhibit the relation of forces; and that not only as respects their relative intensity, but also in other particulars. The *direction of motion* resulting from the application of a given force may always be represented by a straight line drawn from the point at which the motion commences toward the point to which the moving body is impelled. The point at which the force takes effect upon the body is termed the *point of application;* and the *direction of motion* is the path in which the body moves. To this special designations are given appropri-

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Is any object in nature in a state of absolute rest? How may motive powers be classified? What are primary motive powers? Give examples of some that are secondary. How may forces be compared together? How may forces be represented? What is meant by the point of application?

ate to the nature of the case, such as curvilinear, rectilinear, &c.

Moving bodies pass over their paths with different degrees of speed. One may pass through ten feet in a second of time, and another through a thousand in the same interval. We say, therefore, that they have different *velocities.* Such estimates of velocity are obviously obtained by comparing the spaces passed over in a given unit of time. The unit of time selected in natural philosophy is *one second.*

A moving body may be in a state of either uniform or variable motion. In the former case its velocity continually remains unchanged, and it passes over equal distances in equal times. In the latter its velocity undergoes alterations, and the spaces over which it passes in equal times are different. If the velocity is on the increase it is spoken of as a *uniformly accelerated motion.* If on the decrease as a *uniformly retarded motion.* In these cases we mean by the term *initial velocity* the velocity which the body had when it commenced moving, as measured by the space it would then have passed over in one second; and, by the *final velocity*, that which it possessed at the moment we are considering it measured in the same way. The flight of bomb-shells upward in the air is an instance of retarded motion; their descent downward of accelerated motion. The movement of the fingers of a clock is an example of uniform motion.

There are motions of different kinds: 1st, direct; 2d, rotatory; 3d, vibratory.

1st. By direct motion we mean that in which all the parts of the whole body are advancing in the same direction with the same velocity.

2d. By rotatory motion we imply that some parts of the body are going in opposite directions to others. The axis of rotation is an imaginary line, round which the parts of the body turn, it being itself at rest.

3d. By vibratory movement we mean that the body which changes its place returns toward its original position with a motion in the opposite direction. Thus, the

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How are velocities measured? What is the unit of time? What is meant by uniform and what by variable motion? What by initial and final velocity? What varieties of motion are there? What is direct motion? What is rotatory motion? What is vibratory motion?

particles of water which form waves alternately rise and sink, and the pendulum of a clock beats backward and forward. These are examples of vibratory or oscillatory movement.

LECTURE XVI.

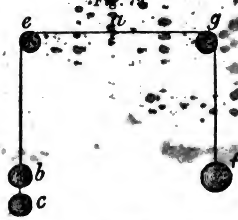
Of the Composition and Resolution of Forces.—*Compound Motion.—Equilibrium.—Resultant.—The Parallelogram of Forces.—Case where there are more Forces than Two.—Parallel Forces.—Resolution of Forces.—Equilibrium of three Forces.—Curvilinear Motions.*

When several forces act simultaneously on a body, so as to put it in motion, that motion is said to be compound.

In cases of compound motion, if the component or constituent forces all act in the same direction, the resulting effect will be equal to the sum of all those forces taken together.

If the constituent forces act in opposite directions, the resulting effect will be equal to their difference, and its direction will be that of the greater force. Thus, if to a knot, *a*, *Fig.* 79, we attach several weights, *b c*, by means of a string passing over a pulley, *e*, these weights will evidently tend to pull the knot from *a* to *e*. But if to the same knot we attach a weight, *f*, by a string passing over the pulley *g*, this tends to draw it in the opposite direction. When the weights on each side of the knot act conjointly, they tend to draw it opposite ways, and it moves in the direction of the greater force.

Fig. 79.



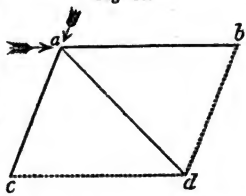
What is compound motion? When the component forces all act in the same direction, what is their effect equal to? What is the result when they act in opposite directions? Under what circumstances are forces in equilibrio?

If two forces of equal intensity, but in opposite directions, act upon a given point, that point remains motionless, and the forces are said to be *in æquilibrio*. When there are many forces acting upon a point in equilibrio, the sum of all those acting on one side must be equal to the sum of all the rest which act in the opposite direction.

By the *resultant* of forces we mean a single force which would represent in intensity and direction the conjoint action of those forces.

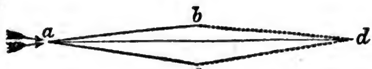
If the constituent forces neither act in the same nor in opposite directions, but at an angle to each other, their resultant can be found in the following manner:—

Fig. 80.



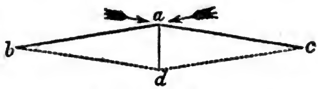
Let *a* be the point on which the forces act; let one of them be represented in intensity and direction by the line *a b*, and the other likewise in intensity and direction by the line *a c*. Draw the lines *b d*, *c d*, so as to complete the parallelogram *a b c d*; draw also the diagonal, *a d*. This diagonal will be the resultant of the two forces, and will, therefore, represent their conjoint action in intensity and direction.

Fig. 81.



The operation of pairs of forces upon a point is readily understood. Thus, 1st. On a point, *a*, *Fig*. 81, let two forces, *a b*, *a c*, act. Complete the parallelogram *a b d c*, and draw its diagonal, *a d*. This line will represent in intensity and direction the resultant force. 2d. On a point, *a*, *Fig*. 82, let two forces again represented in intensity and direction by the lines *a b*, *a c*, act. Complete the parallelogram *a b c d*, draw its diagonal, *a d*, which is the resultant, as before. Now, on comparing *Fig*. 81 with *Fig*. 82, it readily appears that the resultant of two forces

Fig. 82.



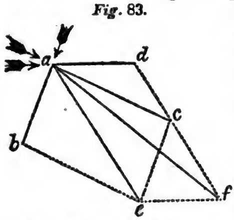
What is meant by a resultant? Describe the parallelogram of forces. Give illustrations of the case in which the forces act nearly in the same, and also of that in which they act nearly in opposite directions.

is greater as those forces act more nearly in the same direction, and less as those forces act more nearly in opposite directions.

Many popular illustrations of the parallelogram of forces might be cited. The following may, however, suffice. If a boat be rowed across a river when there is no current, it will pass in a straight line from bank to bank perpendicularly; but this will not take place if there is a current, for as the boat crosses it is drifted by the stream, and makes the opposite bank at a point which is lower according as the stream is more rapid. It moves in a diagonal direction.

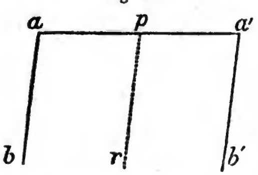
On the same principles we can determine the common resultant of many forces acting on a point. Two of the forces are first taken and their resultant found. This resultant is combined with the third force, and a second resultant found. This again is combined with the fourth force, and so on, until the forces are exhausted. The final resultant represents the conjoint action of all.

Fig. 83.



Thus, let there be three forces applied to the point *a*, represented in intensity and direction by the lines *a b*, *a c*, *a d*, *Fig.* 83, respectively; if *a b* and *a c* be combined, they give as their resultant *a e*, and if this resultant, *a e*, be combined with the third force, *a d*, it yields the resultant *a f*, which, therefore, represents the common action of all three forces.

Fig 84.

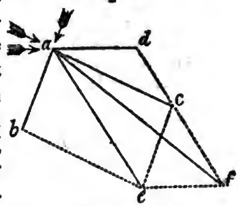


The resultant of two parallel forces applied to a line, and on the same side of it, is equal to their sum and parallel to their direction. Thus, the forces *a b*, *a′ b′* applied to the line *a a′*, give a resultant, *p r*, parallel to their common direction and equal to their sum.

Give an illustration of the diagonal motion of a body under the influence of two forces. How may the resultant of more forces than two be found? What is the resultant of parallel forces applied to a line on the same, and on opposite sides?

But when parallel forces are applied on opposite sides of a line, the resultant is equal to their difference, and its direction is parallel to theirs. In this, as also in the foregoing case, the point at which the resultant acts is at a distance from the points at which the two forces act, inversely proportional to their intensities. In the foregoing case this point falls between the directions of the two forces, and in the latter on the outside of the direction of the greater force.

Fig. 85.



The parallelogram of forces not only serves to effect the composition of several forces, but also the resolution of any given force; that is to assign several forces which in their intensities and directions shall be equivalent to it. Thus, let *a f*, *Fig.* 85, be the given force; by making it the diagonal of a parallelogram it may be resolved into its components, *a d*, *a e;* in the same manner, *a e*, may be resolved into its components, *a c*, *a b*. Thus, therefore, the original force is resolved into three components, *a b*, *a c*, *a d*.

Upon similar principles it may be readily proved that two forces acting at any angle upon a point can never maintain that point in equilibrio—but three forces may; and in this instance, they will be represented in intensity and direction by the three sides of a triangle, perpendicular to their respective directions.

If two forces act upon a point in the direction of and in magnitude proportional to the sides of a parallelogram, that point will be kept in equilibrio by a third force opposed to them in the direction of the diagonal and proportional to it. On the table, *a d*, place a circular piece of paper, on which there is drawn any triangle, *a b c*, *c* coinciding with the center of the table; and let us suppose that the sides of this triangle are, as shown in the figure, in the proportion to one another, as 2 3 4; draw upon the paper, *c e*, parallel to *a b*, and prolong *a c* to *d*. Take three strings, making a knot at the point *c*, and by means of the

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What is meant by the resolution of forces? How does the parallelogram of forces serve for this purpose? Can two forces acting at an angle upon a point keep it in equilibrio? Can three? In this case what must be their relation?

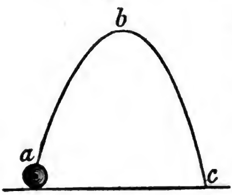
Fig. 86.

movable pullies, *t t t*, stretch the strings over the lines *c b*, *c d*, *c e;* at the end of *c d* suspend a weight of four pounds, at the end of *c e* one of three pounds, and at the end of *c b* one of two pounds. The knot will remain in equilibrio, proving, therefore, the proposition.

In the composition of forces power must always be lost. Thus, in this experiment we see that a weight of three pounds and one of two pounds equipoise a weight of four pounds only.

If of two forces acting upon a point one is momentary and the other constant, the point may move in a curve. Thus, if in *Fig.* 87, a shot be projected obliquely upward from a gun, it is under the action of two forces—the momentary force of the explosion of the gunpowder and the constant effect of the attraction of the earth. It describes, therefore, a curvilinear path, *a b c*, the direction of which continually declines toward the direction of the constant force.

Fig. 87.



It is only when a force acts in a direction perpendicular to a body that its full effect is obtained. This is easily proved by resolving an oblique force into two others, one of which is perpendicular and the other parallel to the side of the body acted upon. This latter force is, of course, lost.

Why in the composition of forces is power always lost? What is the result of the action of a momentary and a constant force upon a point? In what direction must a force act to obtain its full effect?

LECTURE XVII.

INERTIA.—*Inertia a Property of Matter.—Indifference to Motion and Rest.—Moving Masses are Motive Powers.—Determination of the Quantity of Motion.—Momentum.—Action and Reaction.—Newton's Laws of Motion.—Bohnenberger's Machine.*

ALL bodies have a tendency to maintain their present condition, whether it be of motion or rest. It is only by the exertion of force that that condition can be changed. A mass of any kind, when at rest, resists the application of force to put it in motion, and when in motion resists any attempt to bring it to rest. This property is termed INERTIA. It is illustrated by many familiar instances: thus, loaded carriages require the exertion of far more force to put them in motion than is subsequently required to keep them going, and a train of railroad cars will run for a great distance after the locomotive is detached.

Universal experience shows that inanimate bodies have no power to produce spontaneous changes in their condition. They are wholly inactive. Even when in motion they exhibit no tendency whatever to alter their state. Thus, the earth rotates on its axis at the same rate which it did thousands of years ago, and the planetary bodies pursue their orbits with an unchangeable velocity. A moving mass can neither increase nor diminish its rate of speed, for if it could do the former it must necessarily have the power spontaneously to put itself in motion if it were in a condition of rest. Nor can such a mass, if in motion, change the direction of its movement any more than it can change its velocity. Such a change of direction would imply the operation of some innate force, which of itself could have put the mass in movement. Whenever, therefore, we discover in a moving body changes in direction or changes in velocity, we at once impute them

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What is meant by the term inertia? Give an illustration of inertia. What illustration have we that when bodies are in motion they do not spontaneously tend to come to rest? Can a moving mass increase or diminish its rate of speed? Can it change its direction of itself?

to the agency of acting forces, and not to any innate power of the moving body itself.

Fig. 88.

If an ivory ball, *a*, *Fig.* 88, be laid upon a sheet of paper, *b c*, on the table, and the paper suddenly pulled away, the ball does not accompany the movement but remains in the same place on the table.

A person jumping from a carriage in rapid motion falls down, because his body, still participating in the motion of the carriage, follows its direction after his feet have struck the earth.

By the MASS of a body we mean the quantity of matter contained in it—that is, the sum of all its particles. The mass of a body depends on its volume and density.

In consequence of their inertia, masses in motion are themselves motive powers. Such a mass impinging on a second tends to set it in motion.

Fig. 89.

Thus, if a ball *a*, *Fig.* 89, moving toward *c*, impinge upon a second ball, *b*, of equal weight, the two will move together toward *c*, with a velocity one half of that which *a* originally had. In this case, therefore, *a* has acted as a motive force upon *b*, and it is obvious that the intensity of this action must depend on the magnitude and velocity of *a*, increasing as they increase and diminishing as they diminish. The ball *a* is said, therefore, to have a certain *momentum* or *moment*, which depends partly upon its mass and partly upon its velocity; and *the moments of any two bodies may be compared by multiplying together the mass and velocity of each.* Thus, if a body, A, has twice the mass of another, B, and moves with the same velocity, the momentum of A will be twice that of B; but if A, having twice the mass of B, has only half its velocity the moments of the two will be equal.

It is upon this principle that heavy masses moving very slowly exert a great force, and that bodies comparatively light, moving with great speed, produce striking effects. The battering-rams of the ancients, which were heavy masses moving slowly, did not produce more powerful

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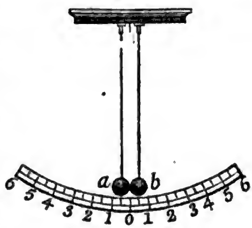
Give an experimental illustration of inertia. How is it that moving bodies are themselves motive powers? How is the quantity of motion or momentum of a body ascertained?

effects than cannon-shot, which, though comparatively light, move with prodigious speed.

From the foregoing considerations, it therefore appears that the amount of motion depends neither upon the mass alone nor the velocity alone. A certain mass, A, moving with a given velocity, has a certain momentum or quantity of motion. If to A a second equal mass, B, with a similar velocity be added, the two conjointly will, of course, possess double the momentum of the first—the mass has doubled, though the speed is the same, and therefore the quantity of motion has doubled. Again, if a certain mass, A, moves with a given speed, and a second one, B, moves with a double speed, it is obvious that this last will have twice the quantity of motion of the former. Here the masses are the same, but the velocities are different. The quantity of motion or momentum which a body possesses is, therefore, obtained by multiplying together the numbers which express its mass and its velocity.

Action and *reaction* are always equal to each other. The resistance which a given body exhibits is equal to the effect of any force operating upon it. This equality of action and reaction may be shown by an apparatus represented in *Fig.* 90, in which two balls of clay or putty, *a b*, are suspended by strings so as to move over a graduated arc. If one of the balls be allowed to fall upon the other, through a given number of degrees, it will communicate to it a part of its motion, and the following facts may be observed: 1st. The bodies, after collision, move on together, and therefore have the same velocity. 2d. The quantity of motion remains unchanged, the one having gained as much as the other has lost, so that if the two are equal they will have half the velocity after impact that the moving one had when alone. 3d. If equal, and moving in opposite directions with equal velocities, they will destroy each other's motions and come

Fig. 90.



Does the mass or the velocity, taken alone, measure the amount of motion? What is the relation between action and reaction? What is the apparatus represented in *Fig.* 90 intended to illustrate? Mention some of the results.

to rest. 4th. If unequal, and moving in opposite directions, they will come to rest when their velocities are inversely as their masses.

The following three propositions are called "Newton's laws of motion." They contain the results depending on inertia:—

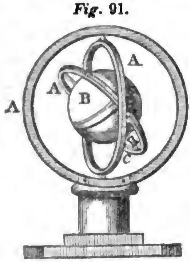
I. Every body must persevere in its state of rest or of uniform motion in a straight line, unless it be compelled to change that state by forces impressed upon it.

II. Every change of motion must be proportional to the impressed force, and must be in the direction of that straight line in which the force is impressed.

III. Action must always be equal, and contrary to reaction, or the action of two bodies upon each other must be equal and directed to contrary sides.

As an example of the operation of inertia, and illustrating the invariability of position of the axis of the earth

Fig. 91.



during its revolution, I here describe Bohnenberger's machine. It consists of three movable rings, A A A, *Fig.* 91, placed at right angles to each other, and in the smallest ring there is a heavy metal ball, B, supported on an axis, which also bears a little roller, *c*. A thread being wound round this roller and any particular position being given to the axis, by quickly pulling the thread the ball may be set in rapid rotation. It is now immaterial in what position the instrument is placed, its axis continually maintains the same direction, and the ring which supports it will resist a considerable pressure tending to displace it.

What are Newton's three laws of motion? Describe Bohnenberger's machine. What does it illustrate?

LECTURE XVIII.

GRAVITATION.—*Preliminary Ideas of Motions of Attraction.—The Earth and Falling Bodies.—Laws of Attraction, as respects Mass and Distance.—Nature of Weight.—Absolute and Specific Weight.—The Plumb-Line.—Convergence of such Lines toward the Earth's Center.—Action of Mountain Masses.*

ALL material substances exert upon each other an attractive force. To this the designation of GRAVITY or GRAVITATION has been given. It was the great discovery of Sir I. Newton that the same force which produces the descent of a stone to the ground holds together the planets and other celestial bodies.

To obtain a preliminary idea of the nature and operation of this force, let us suppose that two balls of equal weight be placed in presence of each other, and under such circumstances that no extraneous agency supervenes to interfere with their mutual action. Under these circumstances, all the phenomena of nature prove that the two balls will commence moving toward each other with equal speed, their velocity continually increasing until they come in contact. Inasmuch, therefore, as their masses are equal and their velocities equal, the quantities of motion they respectively possess will also be equal, as is proved in Lecture XVII.

Again, let there be two other balls situated as before, but let one of them, B, be twice as large as A. Motion will again ensue by reason of their mutual attraction, and they will approach each other with a velocity continually increasing. In this instance, however, their speed will not be equal, the larger body, B, having a correspondingly less velocity than the smaller one, A. If, as we have supposed, it is twice as large, its

Fig. 92.

What is meant by gravity? Give an explanation of the phenomena of the attraction of two equal balls. Give a similar explanation in the case where the balls are unequal.

velocity will be only one half. But in this, as in the former case, the quantity of motion that each possesses is the same, for that depends on velocity and mass conjointly.

Further, if of the two bodies one becomes infinitely great as respects the other, then it is obvious that the little one alone will appear to move. This condition is what actually obtains in the case of our earth and bodies subjected to its influence. A mass of any kind, the support of which is suddenly removed, falls at once to the ground, and though in reality the earth moves to meet it just as much as it moves to meet the earth, the difference in these masses is so immeasurably great that the earth's motion is imperceptible and may be wholly neglected.

The force by which bodies are thus solicited to move to the earth is called terrestrial gravity or gravitation.

The force of gravity depends on two different conditions: 1st, the mass; 2d, the distance.

1st. The intensity of the force of gravity is directly as the mass. That is to say, that, for example, in the case of the earth, if its mass were twice as large its force of attraction would be twice as great; or if it were only half as large its attraction would be only half as much as it is.

2d. In common with all other central forces, gravity diminishes as the distance increases. The law which determines this is expressed as follows: "The force of gravity is inversely as the square of the distance;" that is to say, if a body be placed two, three, four, five times its original distance from another, the force attracting it will continually diminish, and in those different instances will successively be four, nine, sixteen, twenty-five times less than at first.

When a body, instead of being allowed to fall freely to the earth, is supported, its tendency to descend is not annihilated, but it exerts upon the supporting surface a degree of pressure. This pressure we speak of as WEIGHT. And inasmuch as the attractive force upon a body depends on its mass, it is obvious that, if the mass is doubled, the weight is doubled; if the mass is tripled, the weight is

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What is the relation in this respect between falling bodies and the earth? On what two conditions does the intensity of gravity depend? What is the law for the mass? What is the law for the distance? What is weight?

tripled. Or, in other words, the weight of bodies is always proportional to their mass.

The absolute weight of a given body at the same place on the earth's surface is always the same; for the mass, and, therefore, the attractive force of the earth never changes. If by any means the attractive influence of the earth could be doubled, the weight of every object would change, and be doubled correspondingly.

The absolute weight of bodies is determined by balances, springs, steelyards, and other such contrivances, as will be explained in their proper place. Different units of weight are adopted in different countries, and for different purposes, as the grain, ounce, pound, gramme, &c.

In bodies of the same nature the absolute weight is proportional to the volume. Thus a mass of iron which is twice the volume of another mass will also have twice its weight.

But when we examine dissimilar bodies the result is very different. A globe of water compared with one of copper, or lead, or wood of *the same size* will have a very different weight. The lead will weigh more than the water, and the wood less.

This fact we have already pointed out by the term "*specific gravity*," or specific weight of bodies. And, inasmuch as it is obviously a relative thing or a matter of comparison, it is necessary to select some substance which shall serve to compare other bodies with: for solids and liquids water is taken as the unit or standard of comparison. And we say that iron is about seven, lead eleven, quicksilver thirteen times as heavy as it; or that they have specific gravities expressed by those numbers. The unit of comparison for gaseous and vaporous bodies is atmospheric air.

When an unsupported body is allowed to fall its path is in a vertical line. If a body be suspended by a thread the thread represents the path in which that body would have moved. It occupies a vertical direction, or is perpendicular to the position which would be occupied by

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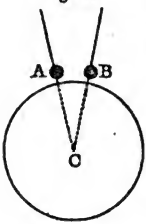
Is it constant for the same body? How is absolute weight determined? What units are employed? What connection is there between weight and volume in bodies of the same kind? What is meant by specific gravity? What substance is the unit for solids and liquids? What is the unit for gases and vapors?

a surface of stagnant water. Such a thread is termed a plumb-line. It is of constant use in the arts to determine horizontal and vertical lines.

Fig. 93.



If in two positions, A B, *Fig.* 93, on the earth's surface plumb-lines were suspended, it would be found that, though they are perpendicular as respects that surface, they are not parallel to one another, but incline, at a small angle, A C B, to each other. If their distance be one mile this convergence would amount to one minute; and if it be sixty miles the convergence would be one degree. Now, as the plumb-line indicates the path of a falling body, it is easily understood that on different parts of the earth's surface the paths of falling bodies have the inclinations just described. A little consideration shows that the descent of such bodies is in a line directed to the center, C, of the earth.

That center we may therefore regard as the active point, or seat of the whole earth's attractive influence.

When examinations with plumb-lines are made in the neighborhood of mountain masses those masses exert a disturbing agency on the plummet, drawing the line from its true vertical position. But this is nothing more than what ought to take place on the theory of universal gravitation; for that theory asserting that all masses exert an attractive influence, the results here pointed out must necessarily ensue, and the lateral action of the mountains correspondingly draw the plummet aside.

What is a plumb-line? At considerable distances from one another are plumb-lines parallel? What conclusion is drawn from this fact? What is the effect of mountain masses?

LECTURE XIX.

THE DESCENT OF FALLING BODIES.—*Accelerated Motion.—Different bodies fall with equal velocities.—Laws of Descent as respects Velocities, Spaces, Times.—Principle of Attwood's Machine.—It verifies the Laws of Descent—Resistance of the Atmosphere.*

OBSERVATION proves that the force with which a falling body descends depends upon the distance through which it has passed. A given weight falling through a space of an inch or two may give rise to insignificant results; but if it has passed through many yards those results become correspondingly greater.

Gravity being a force continually in operation, a falling body must be under its influence during the whole period of its descent. The soliciting action does not take effect at the first moment of motion and then cease, but it continues all the time, exerting as it were a cumulative effect. The falling body may be regarded as incessantly receiving a rapidly recurring series of impulses, all tending to drive it in the same direction. The effect of each one is, therefore, added to those of all its predecessors, and a uniformly accelerated motion is the result.

Falling bodies are, therefore, said to descend with *a uniformly accelerated motion.*

As the attraction of the earth operates with equal intensity on all bodies, *all bodies must fall with equal velocities.* A superficial consideration might lead to the erroneous conclusion that a heavy body ought to descend more quickly than a lighter. But if we have two equal masses, apart from each other, falling freely to the ground, they will evidently make their descent in equal times or with the same velocity. Nor will it alter the case at all if we imagine them to be connected with each other by an inflexible line. That line can in no manner increase or diminish their time of descent.

What is the difference of effect when bodies have fallen through different spaces? Why does gravity produce an accelerated motion? Do all bodies fall to the earth with the same or different velocities?

The space through which a body falls in one second of time varies to a small extent in different latitudes. It is, however, usually estimated at sixteen feet and one tenth.

As the effect of gravity is to produce a uniformly accelerated motion, *the final velocities of a descending body will increase as the times increase;* thus, at the end of two seconds, that velocity is twice as great as at one; at the end of three seconds, three times as great; at the end of four, four times, and so on. Therefore the final velocity at the end

Of the first second is	. . . .	$32\frac{1}{5}$ feet.
" second "	. . . .	$64\frac{2}{5}$ "
" third "	. . . .	$96\frac{3}{5}$ "
&c.,		&c.

The spaces through which the body descends in equal successive portions of time increase as the numbers 1.3.5.7, &c.; that is to say, as the body descends through sixteen feet and one tenth in the first second, the subsequent spaces will be

For the first second	. . . .	$16\frac{1}{10}$ feet.
" second "	. . . .	$48\frac{3}{10}$ "
" third "	. . . .	$80\frac{5}{10}$ "
&c.,		&c.

and these numbers are evidently as 1.3.5, &c.

The entire space through which a body falls increases as the squares of the times. Thus, the entire space is,

For the first second	. . . .	$16\frac{1}{10}$ feet.
" second "	. . . .	$64\frac{2}{5}$ "
" third "	. . . .	$144\frac{9}{10}$ "
&c.,		&c.

and these numbers are evidently as 1.4.9, &c., which are themselves the squares of the numbers 1.2.3, &c.

If a body continued falling with the final velocity it had acquired after falling a given time, and the operation of gravity were then suspended, it would descend in the same length of time through twice the space it fell through before relieved from the action of gravity.

Is the space through which a body descends every where the same? What is the relation between final velocities and times? What relation is there between the spaces and times? What between the entire spaces and times? Suppose a body continues to fall, gravity being suspended, what is the relation of the space through which it will move with that it has already fallen through, the times being equal?

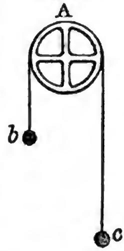
The following table imbodies the results of the three first laws.

Times	1.2.3.4.5.6.7, &c.
Final velocities	2.4.6.8.10.12.14, &c
Space for each time	1.3.5.7.9.11.13, &c.
Whole spaces	1.4.9.16.25.36.49, &c.

It would not be easy to confirm these results by experiments directly made on falling bodies, the space described in the first second being so great (more than sixteen feet), and the spaces increasing as the squares of the times. There is an instrument, however, known as Attwood's machine, in which the force of gravity being moderated without any change in its essential characters, we are enabled to verify the foregoing laws.

The principle of Attwood's machine is this. Over a pulley, A, *Fig.* 94, let there pass a fine silk line which suspends at its extremities equal weights, *b c*. These weights, being equally acted upon by gravity, will, of course, have no disposition to move; but now to one of the weights, *c*, let there be added another much smaller weight, *d*, these conjointly preponderating over *b*, will descend, *b* at the same time rising. It might be supposed that the small additional weight, *d*, under these circumstances, would fall as fast as if it were unsupported in the air; but we must not forget that it has simultaneously to bring down with it the weight to which it is attached, and also to lift the opposite one. By its gravity, therefore, it does descend, but with a velocity which is less in proportion as the difference between the two weights to which it it affixed is less than their sum. It gives us a force precisely like gravity—indeed it is gravity itself—operating under such conditions as to allow a moderate velocity.

Fig. 94.



To avoid friction of the axle of the pulley, each of its ends rests upon two friction-wheels, as is shown at Q, *Fig.* 95; P is the pillar which supports the pulley. One of the weights is seen at *b*, the other moves in front of the divided scale *c d*. This last weight is made to pre-

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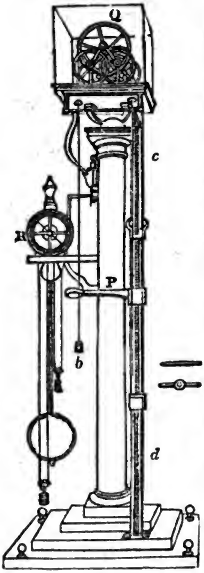
What is the principle of Attwood's machine? Why does not the additional weight fall as fast as if it fell freely? Describe the construction of the machine.

ponderate by means of a rod. There is a shelf which can be screwed opposite any of the divisions of the scale, and the arrival of the descending weight at that point is indicated by the sound arising from its striking. A clock, R, indicates the time which has elapsed. To enable us to fulfill the condition of suspending the action of gravity at any moment, a shelf, in the form of a ring, is screwed upon the scale at the point required. Through this the descending weight can freely pass, but the rod which caused the preponderance is intercepted. The equality of the two weights is, therefore, reassumed, and the action of gravity virtually suspended.

Fig. 95.



By this machine it may be shown that, in order that the descending weight shall strike the ring at intervals of 1, 2, 3, 4, &c., seconds, counting from the time at which its fall commences, the ring must be placed at distances from the zero of the scale, which are as the numbers 1, 4, 9, 16, &c.; and these are the squares of the times. And in the same manner may the other laws of the falling of bodies be proved.

When a body is thrown vertically upward it rises with an equably retarded motion, losing $32\frac{1}{5}$ feet of its original velocity every second. If in vacuo, it would occupy as much time in rising as in falling to acquire its original velocity, and the times expended in the ascent and descent would be the same.

Forces which, like gravity, in this instance, produce a retardation of motion are nevertheless designated as accelerating forces. Their action is such that, if it were brought to bear on a body at rest, it would give rise to an accelerated motion.

Give an illustration of its use. What is the effect when a body is thrown vertically upward? Under what signification is the term "accelerating forces" sometimes used?

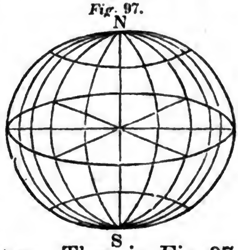
In rapid movements taking place in the atmosphere, a disturbing agency arises in the resistance of the air—a disturbance which becomes the more striking as the descending body is lighter, or exposes more surface. If a piece of gold and a feather are suffered to drop from a certain height, the gold reaches the ground much sooner than the feather. Thus, if in a tall air-pump receiver we allow, by turning the button, *a*, *Fig.* 96, a gold coin and a feather to drop, the feather occupies much longer than the coin in effecting its descent; and that this is due to the resistance of the air is proved by withdrawing the air from the receiver, and, when a good vacuum is obtained, making the coin and the feather fall again. It will now be found that they descend in the same time precisely.

Fig. 96.

Nor is it alone light bodies which are subject to this disturbance: it is common to all. Thus it was found that a ball of lead dropped from the dome of St. Paul's Cathedral, in London, occupied 4½ seconds in reaching the pavement, the distance being 272 feet. But in that time it should have fallen 324 feet, the retardation being due to the resistance of the air.

It has been observed that the force of gravity is not the same on all parts of the earth. The distance fallen through in one second at the pole is 16·12 feet; but at the equator it is 16·01 feet. This arises from the circumstance, that the earth is not a perfect sphere, its polar diameter being shorter than its equatorial and, therefore, bodies at the poles are nearer to its center than they are at the equator. Thus, in *Fig.* 97, let N S represent the globe of the earth, N and S being

Fig. 97.



What cause interferes with these results? How can it be proved that these effects are due to the resistance of the air? Is this disturbance limited to light bodies? What is the distance through which a falling body descends at the equator and at the poles? What is the reason of this difference?

the north and south poles, respectively. Owing to its polar being shorter than its equatorial diameter, bodies situated at different points on the surface may be at very different distances from the center, and the force of gravity exerted upon them may be correspondingly very different.

LECTURE XX.

MOTION ON INCLINED PLANES.—*Case of a Horizontal, a Vertical, and an Inclined Plane.—Weight expended partly in producing pressure and partly motion.—Laws of Descent down Inclined Planes.—Systems of Planes.—Ascent up Planes.*

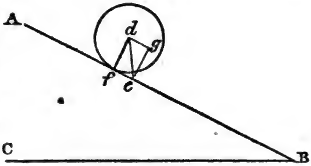
PROJECTILES.—*Parabolic theory of Projectiles.—Disturbing agency of the Atmosphere.—Resistance to Cannon-shot.—Ricochet.—Ballistic Pendulum.*

WHEN a spherical body is placed on a plane set horizontally, its whole gravitation is expended in producing a pressure on that plane. If the plane is set in a vertical position the body no longer presses upon it, but descends vertically and unresisted. At all intermediate positions which may be given to the plane the absolute attraction will be partly expended in producing a pressure upon that plane, and partly in producing an accelerated descent. The quantities of force thus relatively expended in producing the pressure and the motion will vary with the inclination of the plane: that portion producing pressure increasing as the plane becomes more horizontal, and that producing motion increasing as the plane becomes more vertical.

Let there be a ball descending on the surface of an inclined plane, A B, *Fig*. 98, and let the line *d e* represent its weight or absolute gravity. By the parallelogram of forces we may decompose this into two other forces, *d f*

What are the phenomena exhibited by a spherical body placed on planes of different inclinations? Into what forces may the absolute gravity of the body be resolved?

Fig. 98.



and *d g*, one of which is perpendicular to the plane and the other parallel to it. The first, therefore, is expended in producing pressure upon the plane, and the second in producing motion down it.

The following are the laws of the descent of bodies down inclined planes.

The pressure on the inclined plane is to the weight of the body as the base, B C, of the inclined plane is to its length, A B.

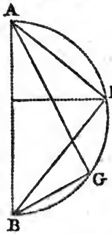
The accelerated motion of a descending body is to that which it would have had if it fell freely as the height, A C, of the plane is to its length, A B.

The final velocity which the descending body acquires is equal to that which it would have had if it had fallen freely through a distance equal to the height of the plane; and, therefore, the velocities acquired on planes of equal height, but unequal inclinations, are equal.

The space passed through by a body falling freely is to that gone over an inclined plane, in equal times, as the length of the plane is to its height.

If a series of inclined planes be represented, in position and length, by the chords of a circle terminating at the extremity of the vertical diameter, the times of descent down each will be equal, and also equal to the time of descent through that vertical diameter. Thus, let A D, A G, D B, G B be chords of a circle terminating at the extremities, A B, of the vertical diameter; and, regarding these as inclined planes, a body will descend from A to D, or A to G, or D to B, or G to B in the same time that it would fall from A to B.

Fig. 99

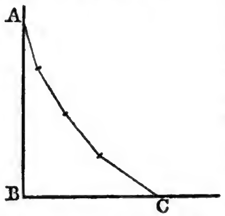


If a body descend down a system of several planes, A

What effects do those forces respectively produce? What relation is there between the pressure on the inclined plane and the weight of the body? What is the relation between the velocities in descent down a plane and free falling? What is the final velocity equal to? What is the relation of the space passed through? What is *Fig.* 99 intended to illustrate?

C, *Fig*. 100, with different inclinations, it will acquire the same velocity as it would have had in descending through the same vertical height, A B, though the times of descent are unequal.

Fig. 100.



If a body which has descended an inclined plane meets at the foot of it a second plane of equal altitude, it will ascend this plane with the velocity acquired in coming down the first, until it has reached the same altitude from which it descended. Its velocity being now expended, it will re-descend, and ascend the first plane as before, oscillating down one plane, up the other, and then back again. The same thing will take place if, instead of being over an inclined plane, the motion be made over a curve, as in *Fig*. 101. In practice, however, the resistance of the air and friction soon bring these motions to an end.

Fig 101.

In the motions of projectiles two forces are involved—the continuous action of gravity, and the momentary force which gave rise to the impulse—such as muscular exertion, the explosion of gunpowder, the action of a spring, &c.

The resulting effects of the combination of these forces will differ with the circumstances under which they act. If a body be projected downward, in a vertical line, it follows its ordinary course of descent, its accelerated motion arising from gravity being conjoined to the original projectile force. But if it be thrown vertically upward, the action of gravity is to produce a uniform retardation. Its velocity becomes less and less, until finally it wholly ceases. The body then descends by the action of the earth, the time of its descent being equal to that of its ascent, its final velocity being equal to its initial velocity.

But if the projectile force forms any angle with the direction of gravity, the path of the body is in a parabolic curve, as seen in *Fig*. 102. If the direction of

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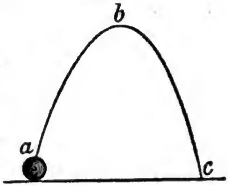
Describe the phenomena of motion on curves. What forces are involved in the motion of a projectile? What are the effects in vertical projection upward and downward? What is the theoretical path in angular projection?

the projection be horizontal, the path described will be half a parabola.

Fig. 102

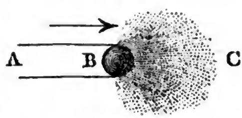


This, which passes under the title of the parabolic theory of projectiles, is found to be entirely departed from in practice. The curve described by shot thrown from guns is not a parabola, but another curve, the Ballistic. In vertical projections, instead of the times of ascent and descent being equal, the former is less. The final velocity is not the same as the initial, but less. Nor is the descending motion uniformly accelerated; but, after a certain point, it is constant. Analogous differences are discovered in angular projections.

The distance through which a projectile could go upon the parabolic theory, with an initial velocity of 2000 feet per second, is about 24 miles: whereas no projectile has even been thrown farther than five miles.

In reality, the parabolic theory of projectiles holds only for a vacuum. And the atmospheric air, exerting its resisting agency, totally changes all the phenomena—not only changing the path, but whatever may have been the initial velocity, bringing it speedily down below 1280 feet per second.

Fig. 103.

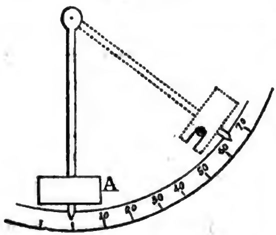


The cause of this phenomenon may be understood from *Fig.* 103. Let B be a cannon-ball, moving from A to C with a velocity more than 2000 feet per second. In its flight it removes a column of air between A and B, and as the air flows into a vacuum only at the rate of 1280 feet per second, the ball leaves a vacuum behind it. In the same manner it powerfully compresses the air in front. This, therefore, steadily presses it into the vacuum behind, or, in other words, retards it, and soon brings its velocity down to such a point that the ball moves no faster than the air moves—that is, 1280 feet per second.

Is this the path in reality? Mention some of the discrepancies between the theoretical and actual movements of projectiles. What are these discrepancies due to? Describe the nature of the resistance exerted on a cannon-shot in its passage through the air.

A shot thrown with a high initial velocity not only deviates from the parabolic path, but also to the right and left of it, perhaps several times. A ball striking on the earth or water at a small angle, bounds forward or *ricochets*, doing this again and again until its motion ceases.

Fig. 104.



The initial velocity given by gunpowder to a ball, and, therefore, the explosive force of that material may be determined by the Ballistic pendulum. This consists of a heavy mass, A, *Fig*. 104, suspended as a pendulum, so as to move over a graduated arc. Into this, at the center of percussion, the ball is fired. The pendulum moves to a corresponding extent over the graduated arc, with a velocity which is less according as the weight of the ball and pendulum is greater than the weight of the ball alone.

The explosive force of gunpowder is equal to 2000 atmospheres. It expands with a velocity of 5000 feet per second, and can communicate to a ball a velocity of 2000 feet per second. The velocity is greater with long than short guns, because the influence of the powder on the ball is longer continued.

LECTURE XXI.

OF MOTION ROUND A CENTER.—*Peculiarity of Motion on a Curve.—Centrifugal Force.—Conditions of Free Curvilinear Motion.—Motion of the Planets.—Motion in a Circle.—Motion in an Ellipse.—Rotation on an Axis.—Figure of Revolution.—Stability of the Axis of Rotation.*

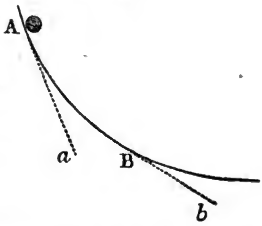
IN considering the motion of bodies down inclined planes, we have shown that the action of gravity upon

What is meant by ricochet? Describe the ballistic pendulum. What is the estimate of the explosive force of gunpowder? What is the velocity of its expansion? What is the velocity it can communicate to a ball?

them may be divided into two portions—one producing pressure upon the plane, and therefore acting perpendicularly to its surface; the other acting parallel to the plane, and therefore producing motion down it.

It has also been shown that, in some respects, there is an analogy between movements over inclined planes and over curved lines, but a further consideration proves that between the two there is also a very important difference. A pressure occurs in the case of a body moving on a curve which is not found in the case of one moving on a plane. It arises from the inertia of a moving body. Thus, if a body commences to move down an inclined plane, the force producing the motion is, as we have seen, parallel to the plane. From the first moment of motion to the last the direction is the same, and inasmuch as the inertia of the body, when in motion, tends to continue that motion in the same straight line, no deflecting agency is encountered.

Fig. 105.



But it is very different with motion on a curve. Here the direction of descent from A to B is perpetually changing; the curve from its form resists, and therefore deflects the falling body. At any point its inertia tends to continue its motion in a straight line: thus, at A, were it not for the curve it would move in the line A *a*, at B in the line B *b*, these lines being tangents to the curve at the points A and B. The curve, therefore, continually deflecting the falling body, experiences a pressure itself—a pressure which obviously does not occur in the case of an inclined plane. This pressure is denominated "centrifugal force," because the moving body tends to fly from the center of the curve.

In the foregoing explanation we have regarded the body as being compelled to move in a curvilinear path, by means of an inflexible and resisting surface. But it may easily be shown that the same kind of motion will

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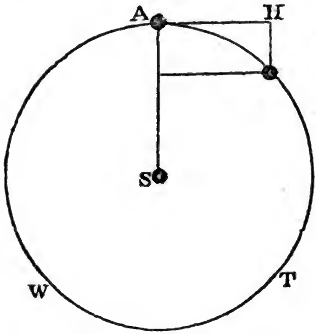
Explain the difference between motion on inclined planes and motion on curves. What is meant by centrifugal force? Under what circumstances can curvilinear motion ensue without the intervention of a rigid curve?

ensue without any such compelling or resisting surface, provided the body be under the control of two forces, one of which continually tends to draw it to the center of the curve in which it moves, while the other, as a momentary impulse, tends to carry it in a different direction.

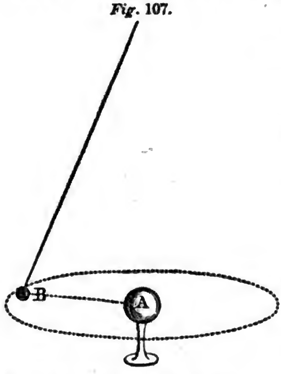
Fig. 106.



Thus, let there be a body, A, *Fig.* 106, attracted by another body, S, and also subjected to a projectile force tending to carry it in the direction A H. Under the conjoint influence of the two forces it will describe a curvilinear orbit, A T W.

The point to which the first force solicits the body to move is termed the center of gravity—that force itself is designated the centripetal force, and the momentary force passes under the name of tangential force.

Fig. 107.



The following experiment clearly shows how, under the action of such forces, curvilinear motion arises. Let there be placed upon a table a ball, A, and from the top of the room, by a long thread, let there be suspended a second ball, B, the point of suspension being vertically over A. If now we remove B a short distance from A, and let it go, it falls at once on A, as though it were attracted. It may be regarded, therefore, as under the influence of a centripetal force emanating from A.

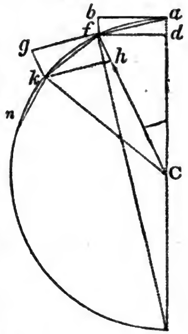
What must the nature of the two forces be? What is the center of gravity? What is the centripetal force? What is the tangential force? Describe the experiment illustrated in *Fig.* 107.

But if, instead of simply letting B drop upon A, we give it an impulse in a direction at right angles to the line in which it would have fallen, it at once pursues a curvilinear path, and may be made to describe a circle or an ellipse according to the relative intensity of the tangential force given it.

This revolving ball imitates the motion of the planetary bodies round the sun.

To understand how these curvilinear motions arise, let C be the center of gravity, and suppose a body at the point *a*. Let a tangential force act on it in such a manner as to drive it from *a* to *b*, in the same time as it would have fallen from *a* to *d*. By the parallelogram of forces it will move to *f*. When at this point, *f*, its inertia would tend to carry it in the direction *f g*, a distance equal to *a f*, in a time equal to that occupied in passing from *a* to *f*; but the constant attractive force still operating tends to bring it to *h*; by the parallelogram of forces it therefore is carried to *k*; and by similar reasoning we might show that it will next be found at *n*, and so on. But when we consider that the centripetal force acts continually, and not by small interrupted impulses, it is obvious that, instead of a crooked line, the path which the body pursues will be a continuous curve.

Fig. 108.



The planets move in their orbits round the sun, and the satellites round their planets, in consequence of the action of two forces—a centripetal force, which is gravitation, and a tangential force originally impressed on them.

The centrifugal force obviously arises from the action of the tangential. It is the antagonist of the centripetal force.

The figure of the curve in which a body revolves is determined by the relative intensities of the centripetal and tangential forces. If the two be equal at all points the curve will be a circle, and the velocity of the body will

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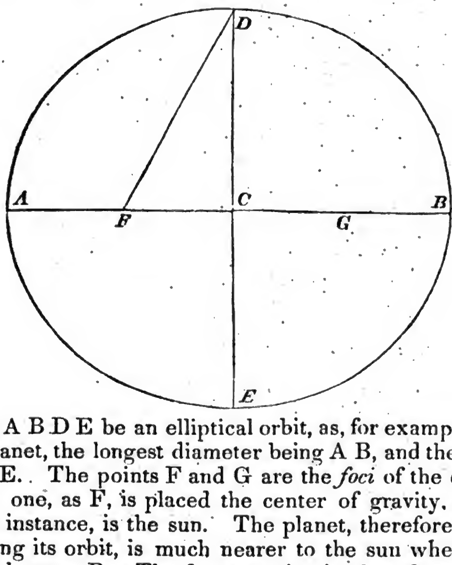
Explain why this curvilinear motion ensues. What forces direct the motions of the planets? What is the relation between the centripetal and centrifugal force?

be uniform. But if the centrifugal force at different points of the body's orbit be inversely as the square of its distance from the center of gravity, the curve will be an ellipse and the velocity of the body variable.

In elliptical motion, which is the motion of planetary bodies, the center of gravity is in one of the foci of the ellipse. All lines drawn from this point to the circumference are called *radii vectores*, and the nature of the motion is necessarily such that the *radius vector* connecting the revolving body with the center of gravity sweeps over equal areas in equal times.

The squares of the velocities are inversely as the distances, and the squares of the times of revolution are to each other as the cubes of the distances.

Fig. 109.



Let A B D E be an elliptical orbit, as, for example, that of a planet, the longest diameter being A B, and the shortest D E. The points F and G are the *foci* of the ellipse, and in one, as F, is placed the center of gravity, which, in this instance, is the sun. The planet, therefore, when pursuing its orbit, is much nearer to the sun when at A than when at B. The former point is, therefore, called the *perihelion*, the latter the *aphelion*, and D and E points

By what circumstance is the figure of the curve determined? Under what circumstances is it a circle? Under what an ellipse? What is the radius vector? What are the laws of elliptic motion?

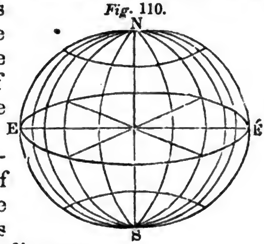
of *mean distance.* The line A B, joining the perihelion and aphelion, is the *line of the apsides ;* it is also the greater or *transverse axis* of the orbit, and D E is the *conjugate* or less axis. A line drawn from the center of gravity to the points D or E, as F D, is *the mean distance,* F is the *lower focus,* G the *higher focus,* A the *lower apsis,* B the *higher apsis,* and F C or G C—that is the distance of either of the foci from the center—*the excentricity.*

When a body rotates upon an axis all its parts revolve in equal times. The velocity of each particle increases with its perpendicular distance from the axis, and, therefore, so also does its centrifugal force. As long as this force is less than the cohesion of the particles, the rotating body can preserve itself, but as soon as the centrifugal force overcomes the cohesive, the parts of the rotating mass fly off in directions which are tangents to their circular motion.

There are many familiar instances which are examples of these principles. The bursting of rapidly rotating masses, the expulsion of water from a mop, the projection of a stone from a sling.

If the parts of a rotating body have freedom of motion among themselves, a change in the figure of that body may ensue by reason of the difference of centrifugal force of the different parts. Thus, in the case of the earth, the figure is not a perfect sphere, but a spheroid, the diameter or axis upon which it revolves, called its polar diameter, is less than its equatorial, it having assumed a flattened shape toward the poles and a bulging one toward the equator. At the equator the centrifugal force of a particle is $\frac{1}{289}$ of its gravity. This diminishes as we approach the poles, where it becomes 0. The tendency to fly from the axis of motion has, therefore, given rise to the force in question.

Fig. 110.

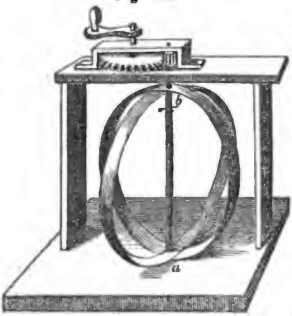


In *Fig.* 110, we have a representation of the general figure of the earth, in which N S is the polar diameter and also the axis of rotation, E′E, the equatorial diameter.

Define the various parts of an elliptic orbit. Describe the phenomena of rotation on an axis. What figure does a movable rotating mass tend to assume?

This may be illustrated by an instrument represented

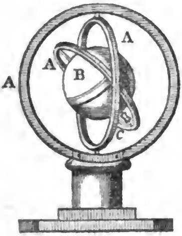
Fig. 111.



in *Fig.* 111, which consists of a set of circular hoops, made of brass or other elastic material. They are fastened upon an axis at the point *a*, but at the point *b* can slide up and down the axis. When at rest they are of a circular form. By a multiplying-wheel a rapid rotation can be given them, and when this is done they depart from the circular shape and assume an elliptical one, the shorter axis being the axis of rotation.

But if the parts of the rotating body have not perfect

Fig. 112.



freedom of motion among themselves, their centrifugal force gives rise to a pressure upon the axis. If the mass is symmetrical as respects the axis, the resulting pressures compensate each other. But as each one of the rotating particles, by reason of its inertia, has a disposition to continue its motion in the same plane, it is obvious that such a *free axis* can only be disturbed from its position by the exercise of a force sufficient to overcome that effect. It is this result which is so well illustrated by Bohnenberger's machine (*Fig.* 112), already described.

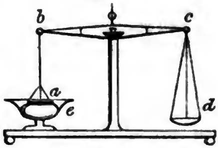
What does the instrument, *Fig.* 111, illustrate? Under what circumstances does pressure on the axis take place? For what reason does the axis tend to maintain the same direction?

LECTURE XXII.

Of Adhesion and Capillary Attraction.—*Adhesion of Solids and Liquids.—Law of Wetting.—Capillary Attraction.—Elevations and Depressions.—Relations of the Diameter of Tubes.—Motions by Capillary Attraction.—Endosmosis of Liquids and of Gases.*

To the arm of a balance, *b c*, *Fig.* 113, let there be attached a flat circular plate of glass, *a*, and let it be equipoised by the weights in the opposite scale, *d*; beneath it let there be brought a cup of water, *e*, and on lowering the glass plate within an inch, or even within the hundredth part of an inch of the water, no attraction is exhibited; but if the glass and the water are brought in contact, then it will require the addition of many weights in the opposite scale to pull them apart.

Fig. 113.



If the cup, instead of being filled with water, is filled with quicksilver, alcohol, oil, or any other liquid, or if instead of a plate of glass we use one of wood or metal, the same effects still ensue. The force which thus maintains the surface in contact is called "Adhesion."

Adhesion does not alone take place between bodies of different forms. Two perfectly flat plates of glass or marble, when pressed together, can only be separated by the exertion of considerable force. In both this and the former case the absolute force required to effect a separation depends on the superficial area of the bodies in contact.

If, on bringing a given solid in contact with a liquid, the force of adhesion is equal to more than half the cohesive force of the liquid particles for one another, the liquid will adhere to the solid or *wet it*. Thus, the adhe-

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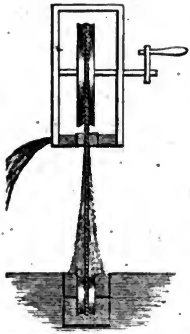
Give an example of the adhesion of a solid to a liquid. Does this take place when liquids of different kinds are used? Does it take place when two solids are employed? Under what circumstances does a liquid wet or not wet a solid?

sive force developed when gold is brought in contact with quicksilver is more than half the cohesion of the particles of the quicksilver for each other: the quicksilver, therefore, adheres to or wets the gold.

Fig. 114.

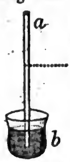


But if the force of adhesion developed between a solid and liquid is less than half the cohesive force of the particles of the latter, the liquid does not wet the solid. Thus, a piece of glass in contact with quicksilver is not wetted.

It is on these principles that Vera's pump acts. It consists of a cord which passes over two wheels, to which a rapid motion can be given. The water adheres to the cord and is raised by it.

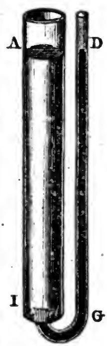
If the surface of some water be dusted over with lycopodium seeds, the fingers may be plunged in it without being wetted, the lycopodium preventing any adhesion of the water.

Fig. 115.



But it is in the phenomena of capillary attraction that we see the effects of adhesion in the most striking manner. These phenomena are exhibited by tubes of small diameter, called capillary tubes, because their bore is as fine as a hair. If such a tube, *a*, *Fig.* 115, be immersed in water, the water at once rises in it to a height considerably above its level, in the glass cup, *b*.

Fig. 116.



Or if instead of water we fill the glass cup with quicksilver, and immerse the tube in it, bringing it near the side so that we can see the metal in the interior of the tube through the glass, it will be found to be depressed beneath its proper level.

These experiments are still more conveniently made by means of tubes bent in the form of a syphon, as represented in *Fig.* 116. If one of these, A I, be partially filled with water, and

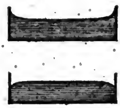
What is the principle of the action of Vera's pump? What is a capillary tube? What phenomenon do these tubes exhibit?

then with quicksilver, the water will be seen to rise in the narrow tube, G D, above its level in the wide tube, A I, and the quicksilver to be depressed.

When tubes of different diameters are used, the change in the level of the liquid is different. The narrower the tube the higher will water rise, and the lower will quicksilver be depressed.

When tubes are very wide, or, what comes to the same thing, when liquids are contained in bowls or basins, the surface is found not to be uniformly level; but near those points where it approaches the glass, in the case of water, it curves upward as seen at A, *Fig.* 117, and in the case of quicksilver it curves downward as seen at B.

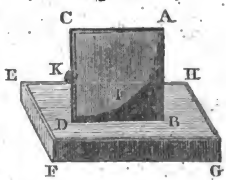
Fig. 117.



In tubes of the same material dipped in the same liquid, the elevations or depressions are inversely as the diameters of the tubes, the narrower the tube the higher will water rise, and the deeper will quicksilver be depressed.

There is a beautiful experiment which shows the connection between the diameter of the tube and the height to which it will lift a liquid. Two square pieces of plate glass, A B, C D, *Fig.* 118, are arranged so that their surfaces form a minute angle. This position may be easily given them by fastening them together with a piece of wax or cement, K. When the plates are dipped into a trough of water, E F, G H, the water rises in the space between them to a smaller extent where the plates are far apart, and to a greater where they are closer. The upper edge of the water gives the form of a hyperbola, D I A. The plates may be supposed to represent a series of capillary tubes of diameters continually decreasing, they show that the narrower the intercluded space or bore of such tubes the higher the liquid will rise.

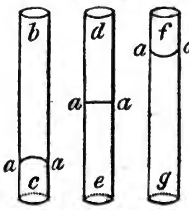
Fig. 118.



The figure of the surface which bounds a liquid in a

Does this depend on the width of the tube? How does the experiment of *Fig.* 118 illustrate this?

Fig 119.

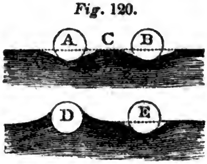


capillary tube is also to be remarked. Whenever a liquid rises in a tube, its bounding surface is concave upward, as seen in *Fig*. 119, where *f g* is the tube, and *a a* the surface. When the liquid neither rises nor sinks, the surface *a a* is plane, as at *d e;* when the liquid is depressed, the surface *a a* is convex upward, as seen at *b c*. All these conditions may be exhibited by a glass tube properly prepared. In such a tube, when quite clean, the concavity and elevation of the liquid is seen; if the interior of the tube be slightly greased, the surface of the water in it is plane, and it coincides in position with the level on the exterior. If it be not only greased, but also dusted with lycopodium, the liquid is depressed in it, and has a convex figure.

It may be shown, according to the principles of hydrostatics, that it is the assumption of this curved surface which is the cause of the elevation or depression of liquids in capillary tubes.

Motions often ensue among floating bodies in consequence of capillary attraction. At first sight they might seem to indicate the exertion of direct forces of attraction and repulsion emanating from the bodies themselves; but this in reality is not the case, the motions arising in consequence of a disturbance of the figure of the surface on which the bodies float.

Fig. 120.



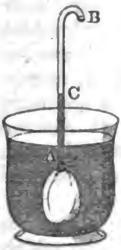
Thus, if we grease two cork balls, A B, and dust them with lycopodium powder, they will, when set upon water, repel the liquid all round, each ball reposing in a hollow space. If brought near to each other, their repulsion exerted on the water at C makes a complete depression, and they fall toward one another as though they were attracting each other. It is, however, the lateral pressure of the water beyond which forces them together.

Under what circumstances is the boundary surface concave, plane, and convex? What is it that determines the elevation or depression of the liquid? Describe the motions which take place in floating bodies in consequence of these facts.

Again, if one of the balls, E, is greased and dusted with lycopodium, and the other, D, clean, and therefore capable of being moistened, an elevation will exist all round D, and a depression round E. When placed near together the balls appear to repel each other, the action in this case, as in the former, arising from the figure of the surface of the water.

If we take a small bladder, or any other membranous cavity, and having fastened it on a tube open at both ends, A B, *Fig.* 121, fill the bladder and tube to the height, C, with alcohol, and then immerse the bladder in a large vessel of water; it will soon be seen that the level at C is rising, and at a short time it reaches the top of the tube at B, and overflows. This motion is evidently due to the circumstance that the water percolates through the bladder, and the phenomenon has sometimes been called endosmosis, or inward movement. Examination proves that while the water is thus flowing to the interior, a little of the alcohol is moving in the opposite way; but as the water moves quicker than the alcohol, there is an accumulation in the interior of the bladder, and, consequently, a rise at C.

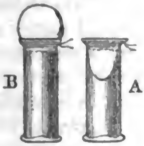
Fig. 121.



One liquid will thus intrude itself into another with very great force. A bladder filled full of alcohol, and its neck tightly tied, will soon burst open if it be plunged beneath water.

Similar phenomena are exhibited by gases. If a jar be filled with carbonic acid gas, and a piece of thin India-rubber tied over it, the carbonic acid escapes into the air through the India-rubber, which becomes deeply depressed as at A, *Fig.* 122. But if the jar be filled with air, and be exposed to an atmosphere of carbonic acid, this gas, passing rapidly through it, accumulates in the interior of the vessel, and gives to the India-rubber a convex or dome-shaped form, as seen at B.

Fig. 122.



Endosmosis is nothing but a complex case of common capillary attraction.

Under what circumstances does repulsion take place? What is meant by endosmosis? Do gases exhibit these properties? Give an illustration of it.

The facts here described were originally discovered by Priestley; but at a later period attention was called to them by Dutrochet, who, regarding them as being due to a peculiar physical principle, gave to the movements in question the names of endosmose and exosmose, meaning inward and outward motion. But I have shown that there is no reason to revert to any peculiar physical principle, since the laws of ordinary capillary attraction explain every one of the facts.

The bursting of a bladder filled with alcohol and sunk under water gives us some idea of the power with which the latter liquid forces its way into the membranous cavity; and it is surprising with what a degree of energy these movements are often accomplished. An opposing pressure of two or three atmospheres seems to offer no obstacle whatever, and I have seen gases pass through India-rubber to mingle with each other, though resisted by pressures of from twenty to fifty atmospheres.

Whenever liquids which can commingle are placed on opposite sides of a membrane or cellular body which they can wet, motion ensues; both liquids simultaneously moving in opposite directions, and commonly one much faster than the other. Thus, if a bladder full of gum-water is immersed in common water, the latter will find its way into the former against any pressure whatever.

During the growth of trees, the terminations of their roots, which are of a soft and succulent nature, and which pass under the name of *spongioles*, are filled with a gummy material which originally was formed in the leaves. The moist or wet soil with which the *spongioles* are in contact, continually furnishes a supply of water which enters those organs in precisely the same way that it would enter a bladder full of gum-water. An accumulation takes place in the organs, and the liquid rises in the vascular parts of the root and the stem, which are in connection therewith. To this we give the name of *ascending sap.* It makes its way to the leaves, there to be changed into gum-water by the action of the light of the sun. It is immaterial how high a tree may be, the force now under consideration is competent to lift the sap to any altitude.

With what degree of force are these motions accomplished? What is the cause of the rise of the sap?

PROPERTIES OF SOLIDS.

LECTURE XXIII.

General properties of Solids.—*Distinctive Properties.—Changes by particular Processes.—Absolute Strength.—Lateral Strength.—Resistance to Compression.—Torsion.—Torsion Balance.*

A substance which can of itself maintain an independent figure has already been defined as a solid body. This peculiarity arises from the relative intensity of the attractive and repulsive forces which obtain among its particles. In solids the attractive predominates over the repulsive force; in liquids there seems to be little difference in their intensity; in gases the repulsive force prevails. It is further to be observed, that portions of gas uniformly mix with each other; the same also takes place with liquids of a similar kind; but when a fragment is broken from a solid mass mere coaptation will not effect reunion.

The cohesive force of solids is exhibited in very different degrees—some solids being brittle, and some ductile—some are hard, and others soft. Thus glass and bismuth may be pulverized in a mortar; but gold can be beaten out to an incredible extent by a hammer, and copper drawn into fine wires. The diamond is the hardest of all substances known, and, from their possessing the same quality, rhodium and iridium are used for the tips of metallic pens, while other solids, such as potassium, sodium, butter, are soft, and yield to a very moderate pressure.

Mention some of the peculiarities of solid bodies. Give examples of brittleness, hardness, and softness.

It has already been stated that the special properties which bodies possess can often be changed by proper processes. Thus glass, by slow cooling, loses much of its brittleness; and steel may be made excessively hard by being ignited and then plunged in cold water. Prince Rupert's drops furnish an illustration of these effects; they are made by suffering drops of melted glass to fall in water. The drop takes on a pear-shaped form, terminating in a long thread. It will stand a tolerably heavy blow on the thick part, but bursts to dust if the tip of the thin part is broken.

Solid substances differ very much in the important peculiarity of STRENGTH. Of all bodies steel is the strongest. The strength of materials may be considered in four ways:—

1st. Absolute strength, or the resistance exerted against a force tending to tear asunder.

2d. Lateral or respective strength—the resistance exerted against being broken across.

3d. Resistance to compression—that is to a force tending to crush.

4th. Strength of torsion—the resistance against separation by being twisted.

The absolute strength of a body may be determined by fastening its upper end and attaching weights to the lower till it breaks. The absolute strength is not affected by the length of a body, but is proportional to the area of its section. A rod of tempered steel, the area of which is one inch, requires nearly 115,000 lbs. to tear it asunder. The strength of cords depends on the fineness of the strands; damp cordage is stronger than dry. Silk cords, of the same diameter, have thrice the strength of those of flax, and a remarkable increase of power arises from gluing the threads together. A hempen cord, the threads of which are glued, is stronger than the best wrought-iron.

The lateral strength of a beam of the shape of a parallelopipedon and of uniform thickness, supported at its

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Can these properties be changed? What phenomenon do Prince Rupert's drops exhibit? What is meant by absolute strength? What by lateral? What by resistance to compression? What by torsion? How may absolute strength be determined? Upon what does it depend? What is the law of lateral strength of rectangular beams?

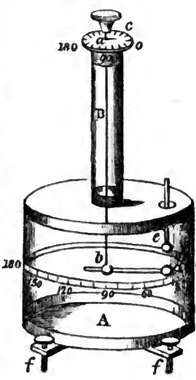
ends and loaded in the middle, is inversely as the length and directly as the product of the breadth into square of the depth. This strength is least when the whole weight acts at the middle, and is greatest when at the ends.

The resistance to compression increases as the section of the body increases, and it diminishes as the body becomes longer. When the body is only a thin plate, its resistance to compression is, however, very small; but it rapidly increases with increasing thickness—reaches a maximum, and then diminishes as the square of the length. This species of resistance is called into operation in the construction of pillars or columns.

Torsion resistance is connected with the elasticity of a body. As respects this force, elasticity, we have already defined it, and shown that no solid substance is perfectly elastic, though gases are. Each solid has its own limit of elasticity, beyond which, if it be strained, it takes a permanent set or it breaks. The limit of elasticity of glass is the point at which it breaks, and that of iron or copper being reached, the metal takes a permanent set.

The resistance arising from elasticity is proportional to the displacement of the particles of the elastic body.

Fig. 123.



The application of this law is involved in several valuable philosophical instruments, among which may be mentioned the torsion balance, used for the determination of weak electric or magnetic forces.

THE TORSION BALANCE consists of a delicate thread of glass or other highly elastic substance, *a b*, *Fig.* 123, fastened at its upper end, *a*, to a button, which turns stiffly in the graduated plate, *c*, and to its lower end at *b*, a lever, *b d*, is affixed transversely. The thread is inclosed in a glass tube, B, and the transverse lever moves in a glass cylinder, A. It is thus protected from the disturbance of currents of air. Round this cylinder, from

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What is the law for resistance to compression? With what property is torsion connected? What is the law of resistance by elasticity? Describe the torsion balance.

0 to 180, graduated divisions are marked, and the whole instrument can be leveled by means of screws *f f*.

Suppose, now, it were required to measure any feeble repulsive force as the repulsion of a little electrified ball, *e*. If this ball be introduced into the interior of the cylinder through an aperture in the top, as shown in the *Fig.* 123, the index at *c* and the ball at *d* being both at the zero of their respective scales, the repulsion of *e* will drive the movable ball *d* through a certain number of degrees. By twisting the button at *a*, we can compel *d* to go back to its original position; and the number of degrees through which the thread must be twisted to effect this, measures the repulsive force for the angle of torsion is always proportional to the force exerted. Of all methods for determining feeble forces in a horizontal plane, the torsion balance is the most delicate and accurate.

LECTURE XXIV.

THE CENTER OF GRAVITY.—*Definition of the Center of Gravity.—Line of Direction.—Position of Equilibrium.—Three Conditions of Support.—Resulting States of Equilibrium.—Stability of Bodies.—The Floating of Bodies.*

IN every solid body there exists a certain point round which its material particles are arranged so as to be equally acted on by gravity. The gravitating forces soliciting these particles may be regarded as acting in lines which are parallel to one another; for the common point of attraction, the center of the earth, is so distant, that lines, drawn from it to the different particles of any body on its surface, are practically parallel. To this point, thus found in every body, no matter what may be its figure or density, the term "*Center of Gravity*" is applied.

A line which connects the center of gravity with the centre of the earth (or, what is the same thing, a line

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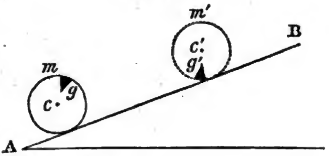
What is meant by the center of gravity of bodies?

drawn from the center of gravity perpendicularly downward) is called "*the line of direction.*" If a solid be suffered to fall, its center of gravity moves along the line of direction until it reaches the ground.

In our reasonings in relation to solids, we may regard them as if all their material particles were concentrated in one point—that point being the center of gravity—this being the point of application of the earth's attraction. It follows, therefore, that if a body has freedom of motion, it cannot be brought into a position of permanent equilibrium until the center of gravity is at the lowest place.

To satisfy this condition, sometimes effects which are apparently contradictory will ensue. Thus, the cylinder, *m*, *Fig.* 124, so constructed, by being weighted on one side, as to have its centre of gravity at the point *g*, while its geometrical center is at *c*, will roll *up* an inclined plane, A B, continuing its motion until, as shown at *m'*, where the center of gravity, *g'*, is in the lowest position.

Fig. 124.



A prop which supports the center of gravity of a body supports the whole body. There are three different positions in which this support may be given :—

1st. The prop may be applied directly to the center itself.

2d. The point of support may have the center immediately below it.

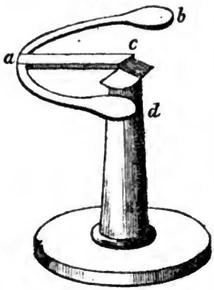
3d. The point of support may have the center immediately above it.

In the first case, when the point of support is directly applied to the center of gravity itself, the body, whatever its figure may be, will remain at rest in any position—as is the case in a common wheel, the center of gravity of which is in the center of its figure, and this being supported upon the axle, the wheel rests indifferently in any position.

Let *b a d*, *Fig.* 125, be a brass semi-circle, weighted

What is the line of direction? What is the position of equilibrium of the center of gravity? In what three positions may the center of gravity be supported? What phenomena arise in the first position?

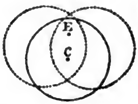
Fig. 125.



at the parts *b d* to such an extent that the center of gravity falls upon the line connecting *b* and *d*. To *a* fasten a light arm, *a c*, long enough to reach to that line, and on this arm, as shown by the figure, the whole body may be balanced.

2d. The point of support may be above the center of gravity. In this case, if the body have freedom of motion, it will not rest in equilibrio until its center of gravity has descended to the lowest position possible, or until it is perpendicularly beneath the point of suspension. Thus, let there be a circular plate, E *c*, *Fig.* 126, the center of gravity of which is at *c*, and let it be suspended at the point E, having freedom of motion on that point. Whatever position we may give it to the right or left, as shown by the dotted lines, it at once moves, and is only at rest when E and *c* are in the same perpendicular line.

Fig. 126.



In the same manner, if a ball be suspended to a point by a thread, whatever position may be given it, there is but one in which it will remain at rest, and that is when its center of gravity is immediately beneath the point of suspension, and the thread in a vertical line.

3d. The point of support may be beneath the center of gravity. In this case, also, the body will be in equilibrio and at rest; but the nature of its equilibrium differs essentially from that of the foregoing case, as we shall presently see. A sphere upon a horizontal plane affords a case in point; and, as its center of gravity is also its center of figure, it will be at rest, no matter what may be the particular point of its surface to which the support is applied.

Upon the principle that if a body be suspended freely, and a perpendicular be drawn from the point of suspension, it will pass through the center of gravity, we are

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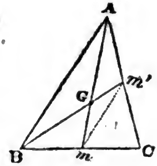
What does the experiment in *Fig.* 125 prove? In the second position of support what are the resulting phenomena? What are those of the third case of support? How may the center of gravity of plane bodies be determined?

Fig. 127.



often enabled to determine the position of that center experimentally. Thus, let the plane body, A B C, *Fig.* 127, be supported by a thread attached to the point A, and to the same point let there be attached a plumb-line: this line, because it is perpendicular, will pass through the center of gravity; let the line A *m*, against which the plumb-line hangs, be marked upon the body. Next, let it be suspended, in like manner, by another point, B, to which the plumb-line is also attached; the direction, B *m'*, of the plumb-line will, in this case, intersect its direction in the former case at some point, such as G. This will be the center of gravity.

When the center of gravity is above the point of suspension, there is produced a pressure upon that point. When the center of gravity is beneath the point of suspension, there is produced a pull upon that point.

The stability of bodies is intimately connected with the position of their center of gravity. A body may be in a condition, 1st, of indifferent; 2d, of stable; 3d, of instable equilibrium.

Indifferent equilibrium ensues when a body is supported upon its center of gravity; for then it is immaterial what position is given to it—it remains in all at rest.

Stable equilibrium ensues when the point of support is above the center of gravity. If the body be disturbed from this situation, it oscillates for a time, and finally returns to its original position.

Instable equilibrium is exhibited when the point of support is beneath the center of gravity. The body being movable, in this instance, it revolves upon its point of support, and turns into such a position that its center of gravity comes immediately beneath that point.

In the theory of the balance, hereafter to be described, these facts are of the greatest importance.

When bodies are supported upon a basis, their stability depends on the position of their line of direction. The

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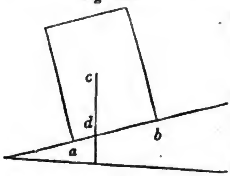
In what case does a pressure and in what a pull upon the point of suspension arise? How many kinds of equilibrium may be enumerated? Under what circumstances do these arise? On what does the stability of bodies depend?

line of direction has already been defined to be a line drawn from the center of gravity perpendicularly downward.

If the line of direction falls within the basis of support, the body remains supported.

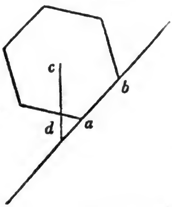
Fig. 128.



If the line of direction falls outside the basis of support, the body overturns.

Thus, let there be a block of wood or metal, *Fig.* 128, of which *c* is the center of gravity, *c d* the line of direction, and let it be supported on its lower face, *a b*. So long as the line of direction falls within this basis, the block remains in equilibrio.

Fig. 129.

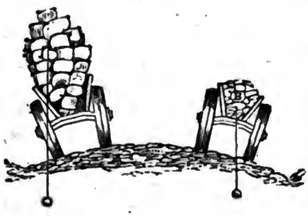


Again, let there be another block, *Fig.* 129, of which *c* is the center of gravity and *c d* the line of direction. Inasmuch as this falls outside of the basis, *a b*, the body overturns.

A ball upon a horizontal plane has its line of direction within its point of support; it therefore rests indifferently in any position in which it may be laid. But a ball upon an inclined plane has its line of direction outside its point of support, and therefore it falls continually.

From similar considerations we understand the nature of the difficulty of poising a needle upon its point. The

Fig. 130.



center of gravity is above the point of support, and it is almost impossible to adjust things so that the line of direction will fall within the basis. The slightest inclination instantly causes it to overturn.

When the center of gravity is very low, or near the

What is the condition for support, and what for being overturned? Illustrate these cases in the instance of square and round blocks. Why is it so difficult to poise a needle on its point? In what circumstances is the maximum stability obtained?

basis, there is more difficulty in throwing the line of direction outside the basis than when it is high. For this reason carriages, which are loaded very high, or have much weight on the top, are more easily overturned than those the load of which is low, and the weight arranged beneath, as is shown in *Fig.* 130.

The stability of a body is greater according as its weight is greater, its center of gravity lower, and its basis wider.

The principles here laid down apply to the case of the flotation of bodies. When an irregular-shaped solid mass is placed on the surface of a fluid, it arranges itself in a certain position to which it will always return if it be purposely overset. In many such solids another position may be found, in which they will float in the liquid; but the slightest touch overturns them. Bodies, therefore, may exhibit either *stable* or *unstable* flotation. A long cylinder floating on one end is an instance of the latter case, but if floating with its axis parallel to the surface of the liquid, of the former.

These phenomena depend on the relative positions of the center of gravity of the floating solid, and that of the portion of liquid which it displaces. The former retains an invariable position as respects the solid mass, but the latter shifts in the liquid as the solid changes its place.

Equilibrium takes place when the center of gravity of the floating body and that of the portion of liquid displaced are in the same line of direction. If of the two the former is *undermost*, stable equilibrium ensues, but if it is *above* the center of gravity of the displaced liquid, unstable equilibrium takes place. To this, however, there is an exception—it arises when the body floats on its largest surface.

There are two forces involved in the determination of the position of flotation: 1st, the gravity of the body downward; 2d, the upward pressure of the liquid. The former is to be referred to the center of gravity of the body itself, and the latter takes effect on the center of gravity of the displaced liquid. If these two centers are

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What is meant by stable and unstable flotation? On what do these depend? Under what circumstances does stable equilibrium take place? Under what unstable? What forces are involved in these results? When does rotation ensue?

in the same vertical line, they counteract each other; but in any other position a movement of rotation must ensue. The solid, therefore, turns over, and finally comes into such a position as satisfies the conditions of equilibrium.

On these principles a cube will float on any one of its faces, and a sphere in any position whatever; but if the sphere be not of uniform density, one part of it being heavier than the rest, motion takes place until the heaviest part is lowest. A long cylinder floating on its end is unstable, but when it floats lengthwise, stable. It is obvious these principles are of great importance in ship-building, and the loading and ballasting of ships.

LECTURE XXV.

THE PENDULUM.—*Simple and Physical Pendulums.—Nature of Oscillatory Motion.—Center of Oscillation.—Laws of Pendulums.—Cycloidal Vibrations.—The Seconds' Pendulum.—Measures of Time, Space, and Gravity.—Compensation Pendulums.*

A SOLID body suspended upon a point with its center of gravity below, so that it can oscillate under the influence of gravity, is called a pendulum.

A simple pendulum is imagined to consist of an imponderable line, having freedom of motion at one end, and at the other a point possessing weight.

A physical pendulum consists of a heavy metallic ball suspended by a thread or slender wire.

The position of rest of a pendulum is when its center of gravity is perpendicularly beneath its point of suspension, its length, therefore, is in the line of direction. If it be removed from this position, it returns to it again after making several oscillations backward and forward. Its descending motions are due to the gravitating action of the earth, its ascending due to its own inertia. A pendulum once in motion would vibrate continually were it not for friction on its point of suspension, the rigidity

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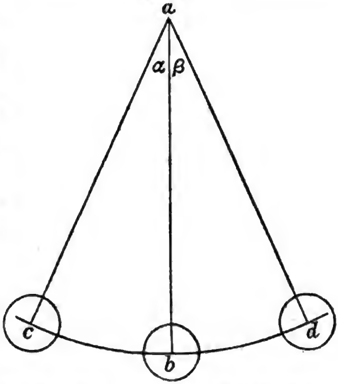
Give examples of the flotation of different bodies. What is a pendulum? What is the difference between a simple and a physical pendulum? What is the position of rest? What is the effect of removal from that position? Why does the instrument eventually come to rest?

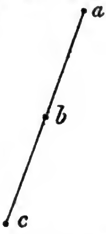
of the thread, if it be supported by one, and the resistance of atmospheric air.

Fig. 131.



The length of a pendulum is the distance that intervenes between its point of suspension and its center of oscillation. Its oscillation is the extreme distance through which it passes from the right hand to the left, or from the left to the right. In *Fig.* 131, *a* is the point of suspension, *b* the center of oscillation; *a b* the length of the pendulum; *c b d* or *d b c* the oscillation; the angle *α* or *β* is the angle of elongation; and the time is the period that elapses in making one complete oscillation. Oscillations are said to be isochronous when they are performed in equal times.

Fig. 132.



Let *a b c*, *Fig.* 132, be a pendulous body, supported on the point *a*, and performing its oscillations upon that point. If we consider the motions of two points, such as *b* and *c*, it will appear that under the influence of gravity the point *b*, which is nearer to the point of suspension, would perform its oscillations more quickly than the point *c*. But inasmuch as in the pendulous body both are supposed to be inflexibly connected together, by reason of the solidity of the mass, both are compelled to perform their oscillations in the same time. The point *b* will, therefore, tend to accelerate the motions of *c*, and *c* will tend to retard the motions of *b*. It follows, therefore, that in every pendulum there is a point the velocity of which, multiplied by the mass of the pendulum, is equal to the quantity of motion in the pendulum.

What is the length of a pendulum, the point of suspension, the oscillation, the angle of elongation, and the time?

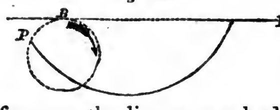
To this point the name of center of oscillation is given. In a linear pendulum—that is, a rod of inappreciable thickness—the center of oscillation is two thirds the length from the point of suspension. In a right-angled conical mass the center of oscillation is at the center of the base.

The center of oscillation possesses the remarkable property that it is convertible with the centre of suspension—that is to say, if a pendulum vibrates in a given time, when supported on its ordinary centre of suspension, it will vibrate in the same time exactly if it be suspended on its center of oscillation. Advantage has been taken of this property to determine the lengths of pendulums, with great precision, and thereby the intensity of gravity and the figure of the earth. In these cases a simple bar of metal, of proper length, with knife-edges equidistant from its ends, has been used and adjustment made until the bar vibrated equally when supported on either knife edge. The distance between the knife-edges is the length of the pendulum.

Pendulums of equal lengths vibrate in the same place in equal times, provided their angles of elongation do not exceed two or three degrees.

Pendulums of unequal lengths vibrate in unequal times —the shorter more quickly than the longer—the times being to one another as the square roots of the lengths of the pendulums.

Fig. 133.



If we take a circle, B, *Fig.* 133, and, causing it to roll along a plane, B D, mark out the path which is described by a point, P, in its circumference, the line so marked is designated a cycloid.

When a pendulum vibrates in a cycloid, it will describe all arcs thereof in equal times; and the time of each oscillation is to the time in which a heavy body would fall through half the length of the pendulum as the circumference of a circle is to its diameter.

The difference, therefore, between oscillation in cy-

Describe the nature of the center of oscillation. What is its position in a linear pendulum and in a right-angled conical mass? What property does the center of oscillation possess? What are the laws of the motion of pendulums? What is a cycloid? What property does a pendulum vibrating in a cycloid possess?

cloidal and circular arcs is, that in the former all oscillations are isochronous, but in the latter they are not; for the larger the circular arc the longer the time of oscillation. And as circular movement is the only one which can be conveniently resorted to in practice, it is necessary to reduce circular to cycloidal oscillations by calculation.

When the length of the pendulum is such that its time of oscillation is equal to one second, it is called a seconds' pendulum. This length differs at different places. Under the equator it is shorter than at the poles; and this evidently arises from the circumstance that the intensity of gravity, as has been already explained, is different at those points; for the figure of the earth not being a perfect sphere but an oblate spheroid, its polar axis being shorter than its equatorial, a body at the poles is more powerfully attracted than one at the equator, it being nearer the center of the earth; and as the motion of the pendulum arises from gravity, in order to make it oscillate in equal times, it is necessary to have it shorter at the equator than at the pole. The length of the seconds' pendulum in London is 39.13929 inches, at a temperature of 60° Fahrenheit.

For many of the purposes of physical science the pendulum is an important instrument. It affords us the best measure of time, and is, therefore, used in all stationary timepieces or clocks. A clock is a mechanical apparatus for the purpose of registering the numbers of oscillations which a pendulum makes, and at the same time of communicating to the pendulum the amount of motion it is continually losing by friction on its points of support and by resistance of the air. The oscillations are performed in small circular arcs, so that the times are equal.

Whatever affects the length of the pendulum changes the time of its motion. It is for this reason that clocks go slower in summer and faster in winter—the changes of temperature altering the length of the pendulum. To compensate this, various contrivances have been resorted to with a view of securing the invariability of the instru-

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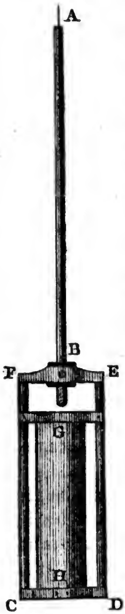
What difference is there between oscillation in cycloidal and circular arcs? What is a seconds' pendulum? Is there difference in its length at different places? From what does this arise? What is the pendulum-clock? Why do variations of temperature change the rate of a clock?

ment. The nature of these is very well illustrated by the mercurial pendulum.

Fig. 134.



Let A B be the pendulum-rod: at B it is formed into a kind of rectangle, F C D E, within which is placed a glass jar, G H, containing mercury, and serving as the bulb of the pendulum. When the weather becomes warm, the steel-rod and rectangle elongate, and therefore depress the center of oscillation. But simultaneously the mercury expands, and this motion takes place necessarily in the upward direction. If the quantity of mercury is properly adjusted the center of oscillation is carried as far upward by the mercurial expansion as downward by that of the steel. Its actual position remains, therefore, the same; and as the length of the pendulum is the distance between the point of suspension and center of oscillation, that length remains unchanged. The gridiron pendulum acts on similar principles.

The pendulum is also used to determine the force of gravity. The nature of this application has already been pointed out in what has been said respecting oscillations at the equator and the poles. The force of gravity at any place, or the height through which a body will fall in one second is determined by multiplying the lengths of a seconds' pendulum for that place by the number 4.9348.

The length of the seconds' pendulum being always invariable at the same place—for gravity is always invariable—may be used as a standard of measure. Thus, the English inch is of such a length that 39.13939 inches are equal to the length of a pendulum vibrating seconds. From these measures of length, measures of capacity might be derived by taking their cubes, and measures of surface by taking their squares.

What contrivances have been resorted to to avoid this difficulty? Describe the mercurial pendulum. On what principle is the pendulum used to determine the force of gravity? Under what circumstances may the pendulum be used as a standard of measure?

LECTURE XXVI.

Of Percussion.—*Of Impact, Central, Excentric, Direct, Oblique.—Inelastic and Elastic Bodies.—Laws of Collision of Inelastic Bodies.—Changes of Figure of Elastic Bodies.—Phenomena of their Collision.—Of Reflected Motions.*

Impact or percussion may take place in several different ways—as central, excentric, direct, oblique.

Central impact takes place when the bodies in collision have their centers of gravity moving in the same right line.

Excentric impact is when the directions of the motion of the centers of gravity of the bodies in collision make an angle with one another.

Direct impact is when the direction of the moving body is perpendicular to the surface on which it impinges.

Oblique impact is when the direction of the moving body makes some angle other than a right one with the surface on which it impinges.

The phenomena of percussion depend greatly on the physical character of the impinging bodies. The bodies may either be inelastic or elastic. Masses of clay or putty are illustrations of the former case, balls of ivory or steel of the latter.

It has already been shown, Lecture XVII, that if two inelastic bodies move in the same direction their joint momentum, after impact, is equal to the sum of their separate momenta; and that, if they move in opposite directions, it is equal to the difference. Their velocity, after impact, is found by dividing their common momentum by the sum of their masses.

When a hard body impinges on an immovable mass, the particles of which can, however, recede, so as to ad-

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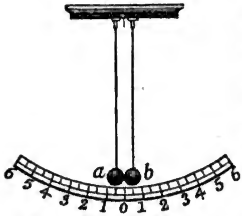
What is central impact? What are excentric, direct, and oblique? On what physical character do the phenomena of percussion, to a great extent depend? Give examples of inelastic and elastic solids. What are the laws of motion of inelastic bodies?

mit the impinging body, the depths to which it will penetrate are as the squares of its velocity multiplied by its mass.

When elastic bodies impinge on each other, there is, during the time of their encounter, a change of figure. Thus, if we take the instrument, *Fig.* 135, and, having painted one of its ivory balls, *a*, let the other ball, *b*, touch it gently, the latter will receive on its surface a single point of paint. But if we raise this ball, and let it fall from a considerable distance upon the other, it will receive a circular mark of paint, showing that, during the percussion, the balls lost their spherical figure, and, instead of touching by a single point, they touched by a surface of considerable extent. Their instantaneous recovery of the spherical form, like the facility with which that form was lost, is due to their elasticity.

Fig. 135.



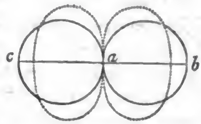
Whatever tends to impair the elasticity of such balls tends, therefore, to change the phenomena of impact. Thus, if we make a cavity in one of them, and fill it partially with lead, the balls, after percussion, will not recede from one another as far as before.

The manner in which elasticity acts in these cases may be understood by considering the action of a spiral spring between the two balls, the length of it coinciding with the direction of their motion. When the balls fall upon its extremities, they give rise to compression, and the spring continually resists them at each successive instant. Their force, which was greatest at the moment of impact, is gradually overcome by the resistance of the spring, and finally vanishes. As soon as their velocity ceases, the spring can undergo no further compression, and is now able to begin to restore itself with a continually increasing force. Finally, it communicates to the balls the same velocity with which they originally impinged upon it.

What is the nature of the change of figure which elastic bodies exhibit when they encounter? How may this be proved? How may it be illustrated by the action of a spring?

When, therefore, a pair of elastic spherical balls are made to impinge on each other, there is a compression of their particles in the direction in which the motion is taking place, so that the diameters, *a b*, *a c*, *Fig.* 136, are less than before. A spheroidal form is, therefore, the necessary result. But just as with the imaginary spring in the foregoing case so with the compressed particles in this. As soon as the motion of the bodies becomes 0, the elastic force of the compressed particles gives rise to movement in the opposite direction.

Fig. 136.



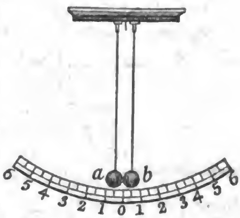
When two perfectly elastic bodies come in collision, the force of elasticity is equal to the force of compression, and the force of compression is equal to the force of the shock.

When two elastic bodies have struck each other, their recession will be with the same *relative* velocity with which they fell upon each other.

When two equal elastic bodies move toward each other with equal velocities, after percussion they recede from each other with the same velocity.

When of two equal elastic bodies one is in motion and the other at rest, the former, after collision, will communicate to the other all its velocity, and remain at rest itself. This phenomenon, and indeed much that is here said in relation to the impact of bodies, is well shown by an apparatus such as *Fig.* 137, in which let the ball, *a*, be at rest, and let *b* fall on it from any height, after collision, *a* takes the whole velocity of *b*, and *b* itself remains at rest.

Fig. 137.



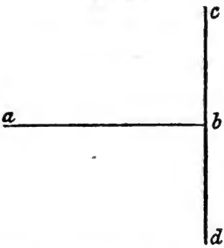
When of two equal bodies, moving in the same direction, one overtakes the other, they exchange velocities and go on as before.

When two equal bodies, moving with different velocities, encounter each other, they exchange, and recede from one another in contrary directions.

What are the laws of motion of perfectly elastic bodies? How may these be proved experimentally?

If, in the instrument *Fig.* 137, instead of having only two ivory balls, we had a large number suspended, so as to touch one another, it would be found, on letting the ball at one extremity impinge on the others, that all the intermediate ones would remain motionless, and the one at the farther extremity would rebound. The motion, therefore, is transmitted through the entire series of balls; and it is the mutual reaction of the intermediate ones which keeps them at rest, the distant one rebounding because there is nothing against which it can react.

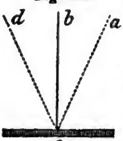
Fig. 138.



When an elastic ball strikes upon an immovable elastic plane it will recoil with the same velocity with which it advanced. When the impact is perpendicular, the path of retrocession is the same as that of advance. Thus, if *a b*, *Fig.* 138, be the path of the advance, perpendicular to *c d*, the elastic plane, the recoil or retrocession will be in the same path, but in the opposite direction, *b a*.

When the path of the striking body is not perpendicular, but at some other angle to the elastic plane the recoil will be under the same angle, but on the opposite side of the perpendicular. Thus, if *a c*, *Fig.* 139, be the path of the striking body, *c*, the elastic plane, the path after contact will be *c*, *d*, such that the points *a c d*, are in the same plane, and the angle *a c b* is equal to the angle *b c d*. To the former of these the name "angle of incidence" is given, to the latter "angle of reflexion."

Fig. 139.



The angle of incidence is the angle included between the path of the impinging body and a perpendicular, *b c*, drawn to the surface of impact at the point of impact And the angle of reflexion is the angle included between the path of the retroceding body and the same perpendicular.

The principles given in this Lecture are applied in

What are the laws of motion of an elastic ball striking upon an immovable elastic plane? What is meant by the angle of incidence? What is the angle of reflexion?

many cases of practice. Thus, in the pile engine, which consists of a heavy block, raised slowly by machinery between two uprights, and then allowed to fall suddenly on the head of the pile to be driven into the ground. If the block thus used as a hammer is too small, it fails to move the pile; and if its velocity is too great it splits the head of the pile. A large mass, falling from a small height, is therefore used. Thus it may be readily shown, that if the hammer weighs 1000 pounds, and it falls through a height of only four feet, the force with which it strikes the pile is equal to 120,000 pounds.

When gold is beaten into thin leaves the workmen cannot employ light hammers and use them quickly, for they would divide or fissure the gold: they use, therefore, heavier hammers, and move them more slowly.

Give some illustrations of the phenomena of impact.

THE ELEMENTS OF MACHINERY.

LECTURE XXVII.

THE MECHANICAL POWERS.—*Definition of Machines.—Number of Mechanical Powers.—Power.—Weight.—Principle of Virtual Velocities.*

THE LEVER—*Definition of.—Three Kinds of Lever.—Conditions of Equilibrium.—Uses of Levers.—The Balance.—Weighing Machines.*

BY MACHINES are meant certain contrivances employed for the purpose of changing the direction of moving powers, or of enabling them to produce any required velocity, or to overcome any required force.

It is to be understood that the force of any moving power can never be increased by the agency of any machine the duty of which is to transmit the effect of that power unimpaired to the working point. Machinery cannot create power—it transmits it. Theoretically, this transmission is supposed to take place without loss, but practically there is always a certain degree of diminution arising both from imperfections of construction and the agency of such impediments to motion as friction, rigidity, &c., the consideration of which we shall resume in its proper place.

In what follows, it will, therefore, be understood that we speak of the action of machines theoretically, and apart from the intervention of these disturbing causes.

All machines, no matter how complex soever their construction may be, can be reduced to one or more of six

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What is meant by a machine? Can machines create power? What is the difference between the theoretical and practical action of machines? How many simple machines are there?

simpler elements, which pass under the name of the "mechanical powers." They are,

The Lever,
Pulley,
Wheel and axle,
Inclined plane,
Wedge,
Screw.

These mechanical powers, or simple machines, may, indeed, be further reduced to three:

The Lever,
Pulley,
Inclined plane.

In any machine the force or original prime-mover passes under the name of THE POWER.

The resistance to be overcome, or that upon which the power is brought to bear through the intervention of the machine, goes under the name of THE WEIGHT.

The general law which determines the equilibrium of all machines, whether simple or compound, is as follows: "*The power multiplied by the space through which it moves in a vertical direction is equal to the weight multiplied by the space through which it moves in a vertical direction.*" The principle involved in this law passes under the name of "the principle of virtual velocities."

The foregoing principle expounding the conditions under which the power and weight are in equilibrium, and the machine, therefore, in a state of rest, it follows, therefore, that "*if the product arising from the power multiplied by the space through which it moves in a vertical direction, be greater than the product arising from the weight multiplied by the space through which it moves in a vertical direction, the power will overcome the resistance of the weight, and motion of the machine will ensue.*"

THE LEVER.

The lever is the first of the elementary machines. In theory, it is an inflexible and imponderable line supported on one point on which it can turn. In practice, it con-

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To what may these be further reduced? What is the power? What is the weight? Describe the general law of equilibrium of all machines. What name is given to the principle contained in this law? Under what condition does motion ensue? What is a lever?

sists of a solid unyielding rod working upon a point called a fulcrum.

Three varieties of lever are commonly enumerated. In the first, the fulcrum, F, is between the power, P, and the weight, W, as in *Fig.* 140. In the second, the weight is between the power and the fulcrum, *Fig.* 141. In the third, the power is between the weight and the fulcrum, *Fig.* 142. There are also other species of lever, such as the bent lever, the curvilinear lever. The mode of action and theory of all are the same.

Fig. 140.

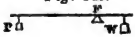


Fig. 141.

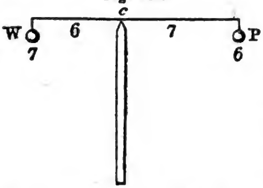
Fig. 142.

By the principle of virtual velocities, it appears that "*any lever is in equilibrio when the power and the weight are to each other inversely as their distances from the fulcrum.*"

As illustrative instances of this—if in a lever of the first kind, *in equilibrio*, the power and the weight are equal, they must be at equal distances from the fulcrum.. If the power is only half the weight, it must be at double the distance from the fulcrum, if one third the weight, triple the distance, &c.

When, therefore, it is proposed by the intervention of a lever to cause a given power to overcome a given weight, it is necessary that the power multiplied by its distance from the fulcrum should give a greater product than the weight multiplied by its distance from the fulcrum. Thus, in *Fig.* 141, let P be a power of six pounds, operating on a lever of the first kind, at a distance, *p c*, from the fulcrum, *c*, of seven inches; let W be the weight to be overcome, and let it be seven pounds, with a distance, W *c*, of six inches from the fulcrum. Now the power multiplied into its distance is equal to forty-two, and the weight multiplied into its distance is also equal to forty-two; the lever is, therefore, under the law just stated in equilibrio. But if we increase the distance of P from *c*, or increase P itself, or do

Fig. 143.



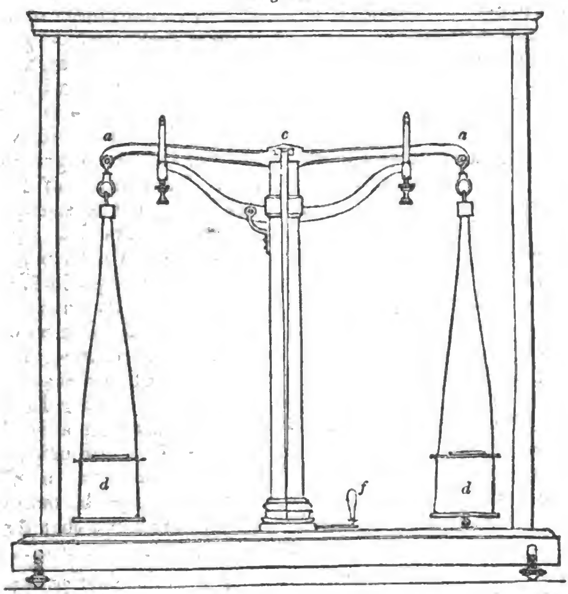
How many varieties of it are there? What is the law of equilibrium of the lever? Give an illustration of it?

both, then the product of P into its distance from the fulcrum will increase, the lever will move, and the resistance of the weight be overcome.

Levers are used in practice for many different purposes. By their agency a small power may hold in equilibrio, or move a great weight; thus, the power of one man applied at the end of a crowbar will overturn a heavy mass, the man acting at a distance of several feet, and the mass at only a few inches from the fulcrum. Of levers of the first kind, crowbars and scissors are familiar examples. Of those of the second kind, oars and nutcrackers; of those of the third, tongs and sheepshears.

For many of the purposes of science levers are used to magnify small motions. The power causing the motion is applied by a short arm near to the fulcrum of the lever,

Fig. 144.



Mention some of the applications of the lever. Give familiar instances of each of the three kinds of lever.

and the other arm, which may be ten, twenty, or more times longer, moves over a graduated scale. The pyrometer is an example of this application.

The most accurate means for determining the weight of bodies is by the lever. When arranged for this purpose, it passes under the name of "The Balance." It is a lever of the first kind with equal arms. Various forms are given to it, and various contrivances annexed for the purpose of insuring its lightness, its inflexibility, and the absolute equality of the lengths of its arms. *Fig.* 144, represents one of the best kinds: *a a* is the beam; *c* is the fulcrum, or center of motion; *d d* are the scale-pans in which the weights and objects to be weighed are applied; their points of suspension are at *a a*. With a view of reducing friction, the axis of motion, *c*, and both the points of suspension are knife-edges of hard steel working on planes of agate; and, to preserve them uninjured, the beam and the scale-pans are supported upon props, except at the time a substance is to be weighed. Then, by moving the handle, *f*, the axis of motion is deposited slowly on its agate plane, and the scale-pans on their points of suspension, and the beam thrown into action.

In balances it is essential that the center of gravity should have a particular position. The cause of this will be appreciated from what has been said in Lecture XXIV. Thus, if the center of gravity coincided with the center of motion, the balance beam would not vibrate, but would stand in a position of indifferent equilibrium, whatever angular position might be given to its arms.

If the centre of gravity was above the axis of motion, the balance would be in a condition of unstable equilibrium, and would overset by the slightest increase of weight on either side, the center of gravity coming down to the lowest point. But when it is beneath the axis of motion, the balance vibrates like a pendulum, and neither sets nor oversets. It is essential, therefore, that in all these instruments the center of gravity should be below the center of motion. And it might be shown that the

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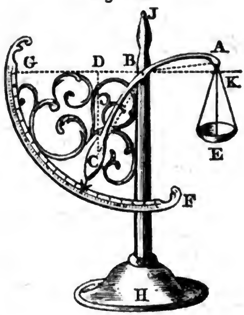
Give an instance of the application of the lever to magnifying small motions. What is a balance? What takes place if the center of gravity coincides with the center of motion? What is the effect when it is above the axis of motion? What when it is beneath? With what does the sensibility of the balance increase?

sensibility of the balance, or, in other words, the smallness of the weight it will detect, becomes greater as these two centers approach each other.

The different kinds of weighing-machines are either modified levers or combinations of levers. Examples occur in the machine for weighing loaded carts, in the steelyard, which is a lever of unequal arms, and in the bent lever balance. The latter is represented in *Fig.* 145. It consists of a bent lever, A B C, the end of which, C, is loaded with a fixed weight. This lever works on a fulcrum, B, supported on a pillar, H J. From the arm, A, is suspended a scale-pan, E, and to the pillar there is affixed a divided scale, F G, over which the lever moves. Through B draw the horizontal line, G K, and let fall from it the perpendiculars, A K, D C. Then, if B K and B D are inversely proportional to the weight in the scale, E, and the fixed weight, C, the balance will be in equilibrio; but if they are not, then the lever moves, C going farther from the fulcrum, and stopping when equilibrium is attained. The scale, F G, is graduated by previously putting known weights in E.

Fig. 145.



LECTURE XXVIII.

THE PULLEY.—*Description of the Pulley.—Laws of the Lever apply to it.—Use of the Fixed Pulley.—The Movable Pulley.—Runners.—Systems of Pulleys.—White's Pulley.*

THE WHEEL AND AXLE.—*Law of Equilibrium.—Advantages over the Lever.—Windlass.—Capstan.—Wheel-work.—Different kinds of Toothed-Wheels.*

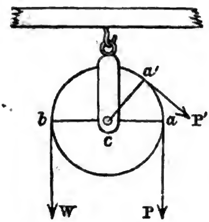
THE pulley is a wheel, round the rim of which a groove is cut, in which a cord can work, and the center of which

Describe the bent lever balance and the steelyard. What is a pulley, its sheave, and its block?

moves on pivots in a block. The wheel sometimes passes under the name of a sheave.

By a *fixed pulley* we mean one which merely revolves on its axis, but does not change its place. The power is applied to one end of the cord and the weight to the other.

Fig. 146.



The action of the pulley may be readily understood from that of the lever. Let *c*, *Fig.* 146, be the axis of the pulley, *b* the point to which the weight is attached, *a* the point of application of the power; draw the lines, *c b*, *c a*—they represent the arms of a lever—and the law of the equilibrium of a lever, therefore, applies in this case also; and, as these arms are necessarily equal to each other, the pulley will be in equilibrio when the weight and power are equal.

If the direction in which the power is applied, instead of being P *a*, is P′ *a′*, the same reasoning still holds good. For, on drawing C *a′*, as before, it is obvious that *b c a* represents a bent lever of equal arms. The condition of equilibrium is, therefore, the same.

The fixed pulley does not increase the power, but it renders it more available, by permitting us to apply it in any desired direction.

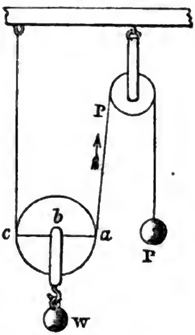
To prove the properties of the pulley experimentally, hang to the ends of its cord equal weights; they will remain in equilibrio. Or, if the power be increased, so as to make the weight ascend, the vertical distances passed over are equal.

The movable pulley is represented at *Fig.* 147. Its peculiarity is that, besides the motion on its own axis, it also has a progressive one. Let *b* be the axis of the pulley, and to it the weight *w* is attached, the power is applied at *a*. Draw the diameter *a c*, then *c* is the fulcrum of *a c*, which is in reality a lever of the third order in which the distance, *a c*, of the power is twice that, *b c*, of the weight. Consequently "the movable pulley doubles

What is a fixed pulley? Describe the nature of its action. What is the result of the action of the fixed pulley? What is a movable pulley? To what extent does it increase the power?

the effect of the power," and the distance traversed by the power is twice that traversed by the weight.

Fig. 147.

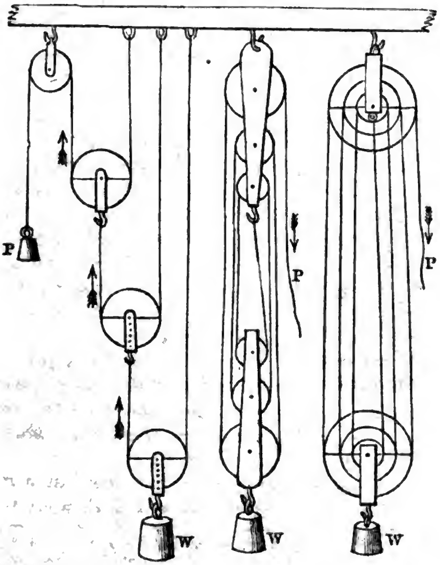


A movable pulley is sometimes called "a runner;" and, as it would be often inconvenient to apply the power in the upward direction, as at *a* P, there is commonly associated with the runner a fixed pulley, which, without changing the value of the power, enables us to vary the direction of its action.

Systems of pulleys are arrangements of sheaves, movable and fixed.

When one fixed pulley acts on a number of movable ones, equilibrium is maintained, when the power and

Fig. 148. *Fig.* 149. *Fig.* 150.



What are systems of pulleys?

weight are to each other as 1 to that power of 2 which equals the number of the movable pulleys. Thus, if there be, as in *Fig.* 148, three movable pulleys, the power is to the weight

$$\text{as } 1 : 2^3 \text{ that is } 1 : 8;$$

consequently, on such a system, a given power will support an eightfold weight.

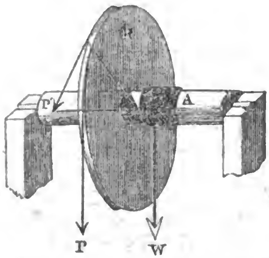
When several movable and fixed pulleys are employed, as in *Fig.* 149, equilibrium is obtained when the power equals the weight divided by twice the number of movable pulleys.

In such systems of pulleys there is a great loss of power arising from the friction of the sheaves against the sides of the blocks, and on their axles. In White's pulley this is, to a considerable extent, avoided. This contrivance is represented in *Fig.* 150. It consists of several sheaves of unequal diameters, all turned on one common mass, and working on one common axis. The diameters of these, in the upper blocks, are as the numbers 2, 4, 6, &c., and in the lower 1, 3, 5, &c.; consequently, they all revolve in equal times, and the rope passes without sliding or scraping upon the grooves.

THE WHEEL AND AXLE.

The wheel and axle consists of a cylinder, A, *Fig.* 151, revolving upon an axis, and having a wheel, R, of larger diameter, immovably affixed to it. The power is applied to the circumference of the wheel, the weight to that of the axle.

Fig. 151.



The law of equilibrium is, that "*the power must be to the weight as the radius of the axle is to that of the wheel.*"

This instrument is, evidently, nothing but a modification of the lever; it may be regarded as a continuously

Give the law of equilibrium when one fixed pulley acts on a system of movable ones. What is it when several movable and fixed ones are employed? Describe White's pulley and the difficulties it avoids. What is meant by the wheel and axle? What is the law of its equilibrium?

acting lever. In its mode of action, the common lever operates in an intermitting way, and, as it were, by small steps at a time. A mass, which is forced up by a lever a short distance, must be temporarily propped, and the lever readjusted before it can be brought into action again; but the wheel and axle continues its operation constantly in the same direction.

That this is its mode of action may be understood from considering *Fig.* 152, in which let c be the common center of the axle $c\,b$, and of the wheel $c\,a$, a the point of application of the power P, and b that of the weight W. Draw the line $a\,c\,b$; it evidently represents a lever of the first order of which the fulcrum is c, and from the principles of the lever it is easy to demonstrate the law of equilibrium of this machine, as just given. Further, it is immaterial in what direction the power be applied, as P′ at the point a' for $a'\,c\,b$ still forms a bent lever, and the same principle still holds good.

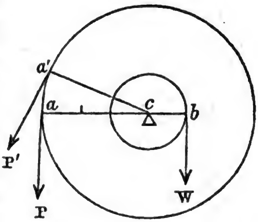


Fig. 152.

Sometimes the wheel is replaced by a *winch*, as in *Fig.* 153, it is then called a *windlass*, if the motion is vertical; but if it be horizontal, as in *Fig.* 154, the machine is called a *capstan*.

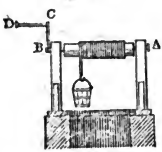


Fig. 153

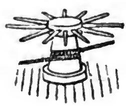


Fig. 154.

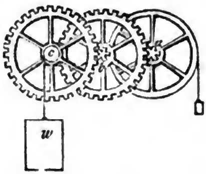
Wheels and axles are often made to act upon one another by the aid of cogs, as in clockwork and mill machinery. In these cases the cogs on the periphery of the wheel take the name of *teeth*, those on the axle the name of *leaves*, and the axle itself is called *a pinion*.

The law of equilibrium of such machines may be easily demonstrated to be, that *the power multiplied by the product of the number of teeth, in all the wheels, is equal to the weight multiplied by the product of the number of leaves in all the pinions.*

Describe its mode of action. What is a windlass and a capstan? What are teeth, leaves, and pinions? What is the law of equilibrium of wheelwork?

A system of wheel and pinion work is represented at *Fig.* 155. It is scarcely necessary to observe, that in it, as in all other cases, the law of virtual velocities holds good—the power multiplied by the velocity of the power is equal to the weight multiplied by the velocity of the weight.

Fig. 155.



In the construction of such machinery attention has to be paid to the form of the teeth, so that they may not scrape or jolt upon one another. Several of them should be in contact at once, to diminish the risk of fracture and the wear.

If the teeth of a wheel be in the direction of radii from its center it is called a spur-wheel.

If the teeth are parallel to the axis of the wheel it is called a crown-wheel.

If the teeth are oblique to the axis of the wheel it is called a beveled-wheel.

By combining these different forms of wheel suitably together, the resulting motion can be transferred to any required plane. Thus, by a pair of beveled-wheels motion round a vertical axis may be transferred to a horizontal one, or, indeed, one in any other direction.

When a pinion is made to work on a toothed-bar, it constitutes a rack. This contrivance is under the same law as the wheel and axle.

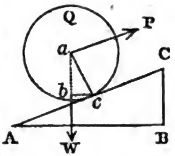
What precautions have to be used as respects the form of teeth? What is a spur, a crown, and a beveled-wheel? How may motion be transferred to different planes? What is a rack?

LECTURE XXIX.

THE INCLINED PLANE.—*Description of the Inclined Plane.—Modes of Applying the Power.—Conditions of Equilibrium when the Power is Parallel to the Plane or Parallel to the Base.—Position of Greatest Advantage.*
THE WEDGE.—*Description and Mode of using it.*
THE SCREW.—*Formation of the Screw.*

BY the inclined plane we mean an unyielding plane surface inclined obliquely to the resistance to be overcome.

Fig. 156



In *Fig.* 156, A C represents the inclined plane; the angle at A is the elevation of the plane; the line A C is the length, C B is the height, A B the base.

In the inclined plane the power may be applied in the following directions:

1. Parallel to the plane;
2. Parallel to its base;
3. Parallel to neither of these lines.

As in the former cases, so in this—the conditions of the equilibrium may be deduced from those of the lever.

Let us take the first instance, when the power is applied parallel to the inclined plane. Let Q, *Fig.* 156, be a body placed upon the plane, A C, the height of which is B C, and the base A B. The weight of this body acts in the vertical direction, *a* W; the body rests on the point, *c*, as on a fulcrum; and the power, P, under the supposition, acts on Q, in the direction *a* P. From the fulcrum, *c*, draw the perpendicular, *c b*, to the line of direction of the weight, *a* W; draw also *c a*. Then does *b c a* represent a bent lever, the power being applied to the point *a*, and the weight at the point, *b*; and, therefore, the power is to the weight as *b c* is to *a c*; but the triangles, *a*

Describe the inclined plane. What is the angle of elevation, the length, the height, and the base? In how many directions may the power be applied?

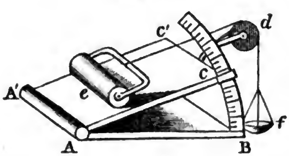
b c, A B C, are similar to each other. Therefore, we arrive at the following law:

When the power acts in a direction parallel to the inclined plane, it will be in equilibrio with the weight when it is to the weight as the perpendicular of the plane is to its length.

In a similar manner it may be shown *that when the power acts parallel to the base it will be in equilibrio with the weight, if it be to the weight as the perpendicular of the plane is to its base.*

In different inclined planes the power increases as the height of the plane, compared with its length, diminishes, and the best direction of action is parallel to the inclined plane. This is very evident from the consideration that if the power be directed above the plane a portion of it is expended in lifting the weight off the plane, while the diminished residue draws it up. If it be directed downward a part is expended in pressing the weight upon the plane, and the diminished residue draws it up. Therefore, if the power acts parallel to the plane, it operates under the most advantageous condition.

Fig. 157.



The laws of the inclined plane may be illustrated by an instrument, such as is represented in *Fig.* 157, in which A *c* A′ *c*′ is the plane, which may be set at any angle. It works upon an axis, A A′. Upon the plane a roller, *e*, moves. It has a string passing over a pulley, *d*, and terminating in a scale-pan, *f*, in which weights may be placed. The direction of the string may be varied, so as to be parallel to the plane, or the base, or any other direction.

The inclined plane is used for a variety of purposes—very frequently for facilitating the movements of heavy loads.

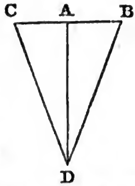
THE WEDGE.

The wedge may be regarded as two inclined planes

What is the law of equilibrium when the power acts parallel to the plane? What is it when the power acts parallel to the base? For what purposes is the inclined plane used? Describe the wedge.

laid base to base—A C D being one, and A B D being the other. The planes B D and C D constitute the sides or faces of the wedge; B C is its back, and A D its length.

Fig. 158.



The mode of employing the wedge is not by the agency of pressure, but of percussion. Its edge being inserted into a fissure, the wedge is driven in by blows upon its back. It is kept from recoiling by the friction of its sides against the surfaces past which it has been forced.

Fig. 159.

This mode of application of the wedge prevents us from comparing its theory with that of the inclined plane—a power to which it has so much external resemblance.

Fig. 161.

The power of the wedge increases as the length of its back, compared with that of its sides, is diminished. As instances of its application, we may mention the splitting of timber, the raising of heavy weights, such as ships. Different cutting-instruments, as chisels, &c., act in consequence of their wedge-shaped form.

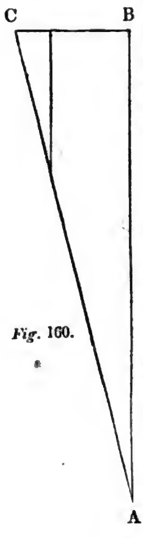


Fig. 160.

THE SCREW.

If we take a piece of paper cut into a long, right-angled triangle, *Fig.* 160, and wind it about a cylinder *Fig.* 161, so that the height C B of the triangle is parallel to the axis, the length A C will trace a screw-line on the surface. The same results if we take a cylinder and wind upon it a flexible cord, so that the strands of the cord uniformly touch one another.

In any screw, the line which is thus traced upon the cylinder goes under the name of the "worm," or "thread," and each complete turn that it makes is called

On what principle does it act? On what does its power depend? How may a screw-thread be represented?

"a spire." The distance from one thread to another, which, of course, must be perfectly uniform throughout the screw, is called the breadth of the worm.

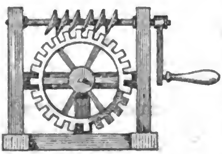
In most cases the screw requires a corresponding cavity in which it may work; this passes under the name of "a nut." Sometimes the nut is caused to move upon the screw, and sometimes the screw in the nut. In either case the movable part requires a lever to be attached, to the end of which the power is applied.

The law of equilibrium of the screw is, that "*the power is to the weight as the breadth of the worm is to the circumference described by that point of the lever to which the power is attached.*

When the end of the screw is advancing through a nut, this law evidently becomes that *the power is to the weight as the circumference described by the power is to the space through which the end of the screw advances.* It is obvious, therefore, that the force of the screw increases as its threads are finer, and as the lever by which it is urged is longer.

When the thread of a screw works in the teeth of a wheel, as shown in *Fig.* 162, it constitutes an endless screw. An important use of this contrivance is in the engine for dividing graduated circles. The screw is also used to produce slow motions, or to measure by the advance of its point, minute spaces. In the spherometer, represented in *Fig.* 5, we have an example of its use.

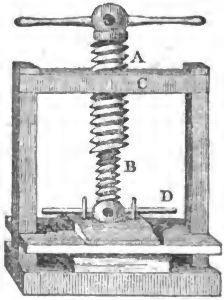
Fig 162.



For all these purposes where slow motions have to be given, or minute spaces divided, the efficacy of the screw will increase with the closeness of its thread. But there is soon a practical limit attained; for, if the thread be too fine it is liable to be torn off. To avoid this, and to attain those objects almost to an unlimited extent, Hunter's screw is often used. It may be understood from *Fig.* 163. It consists of a screw, A, working in a nut, C.

What is the worm and the spire? What is a nut? What is the law of equilibrium of the screw? When the end of the screw advances what does this law become? Describe an endless screw.

Fig. 163.



To a movable piece, D, a second screw, B, is affixed. This screw works in the interior of A, which is hollow, and in which a corresponding thread is cut. While, therefore, A is screwed downward, the threads of B pass upward, and the movable piece, D, advances through a space which is equal to *the difference* of the breadth of the two screws. In this way very slow or minute motions may be obtained with a screw, the threads of which are coarse.

LECTURE XXX.

Of Passive or Resisting Forces.—*Difference between the Theoretical and Actual Results of Machinery.—Of Impediments to Motion.—Friction.—Sliding and Rolling Friction.—Coefficient of Friction.—Action of Unguents.—Resistance of Media.—General Phenomena of Resistance.—Rigidity of Cordage.*

It has already been stated, in the foregoing Lectures, that the properties of machinery are described without taking into account any of those resisting agencies which so greatly complicate their action. The results of the theory of a machine in this respect differ very widely from its practical operation. There are resisting forces or impeding agencies which have thus far been kept out of view. We have described levers as being inflexible, the cords of pulleys as perfectly pliable, and machinery, generally, as experiencing no friction. In the case of one of the powers, it is true that this latter resisting force must necessarily be taken into account; for it is upon it that the efficacy of the wedge chiefly depends.

Describe Hunter's screw. What is meant by passive or resisting forces? Why does the theoretical action of a machine differ from its practical operation?

So, too, in speaking of the motion of projectiles, it has been stated that the parabolic theory is wholly departed from, by reason of the resistance of the air; and that not only is the path of such bodies changed, but their range becomes vastly less than what, upon that theory, it should be. Thus, a 24-pound shot, discharged at an elevation of 45°, with a velocity of 2000 feet per second, would range a horizontal distance of 125,000 feet were it not for the resistance of the air; but through that resistance its range is limited to about 7300 feet.

Of these impediments to motion or passive or resisting forces, three leading ones may be mentioned. They are, 1st, friction; 2d, resistance of the media moved through; 3d, rigidity of cordage.

OF FRICTION.

Friction arises from the adhesion of surfaces brought into contact, and is of different kinds—as *sliding friction*, when one surface moves parallel to the other, *rolling friction*, when a round body turns upon the surface of another.

By the measure of friction, we mean that part of the weight of the moving body which must be expended in overcoming the friction. The fraction which expresses this is termed the coefficient of friction. Thus, the coefficient of sliding friction in the case of hard bodies, and when the weight is small, ranges from one seventh to one third.

It has been proved by experiment that friction increases as the weight or pressure increases, and as the surfaces in contact are more extensive, and as the roughness is greater. With surfaces of the same material it is nearly proportional to the pressure. The time which the surfaces have been in contact appears to have a considerable influence, though this differs much with surfaces of different kinds. As a general rule, similar substances give rise to greater friction than dissimilar ones.

On the contrary, friction diminishes as the pressure is

Give an illustration of resisting force in the case of projectiles. How many of these impediments may be enumerated? What varieties of friction are there? What is the coefficient of friction? Mention some of the conditions which increase friction.

less, as the polish of the moving surfaces is more perfect, and as the surfaces in contact are smaller. It may also be diminished by anointing the surfaces with some suitable unguent or greasy material. Among such substances as are commonly used are the different fats, tar, and black lead. By such means, friction may be reduced to one fourth.

Of the friction produced by sliding and rolling motions, the latter, under similar circumstances, is far the least. This partly arises from the fact that the surfaces in contact constitute a mere line, and partly because the asperities are not abraded or pushed aside before motion can ensue. The nature of this distinction may be clearly understood by observing what takes place when two brushes with stiff bristles are moved over one another, and when a round brush is rolled over a flat one. In this instance, the rolling motion lifts the resisting surfaces from one another; in the former, they require to be forcibly pushed apart.

Though, in many instances, friction acts as a resisting agency, and diminishes the power we apply to machines, in some cases its effects are of the utmost value. Thus, when nails or screws are driven into bodies, with a view of holding them together, it is friction alone which maintains them in their places. The case is precisely the same as in the action of a wedge.

RESISTANCE OF MEDIA.

A great many results in natural philosophy illustrate the resistance which media offer to the passage of bodies through them. The experiment known under the name of the guinea and feather experiment establishes this for atmospheric air. In a very tall air-pump receiver there are suspended a piece of coin and a feather in such a way that, by turning a button, at *a*, *Fig.* 164, the piece on which they rest drops, and permits them to fall to the pump-plate. Now, if the receiver be full of atmospheric air, on letting the objects fall, it will be found that, while the coin descends with rapidity, and reaches, in an instant,

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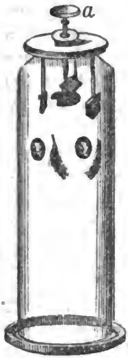
Mention some that diminish it. What is the difference of effect between sliding and rolling friction? Give an illustration of this. Under what circumstances does advantage arise from friction?

Fig. 164.



the pump-plate, the feather comes down leisurely, being buoyed up by the air, and the speed of its motion resisted. But if the air is first extracted by the pump, and the objects allowed to fall in vacuo, both precipitate themselves simultaneously with equal velocity, and accomplish their fall in equal times.

In the vibrations of a pendulum, the final stoppage is due partly to friction and partly to this cause. And in the case of motions taking place in water, we should, of course, expect to find a greater resistance arising from the greater density of that liquid.

The resisting force of a medium depends upon its density, upon the surface which the moving body presents, and on the velocity with which it moves. Water, which is 800 times more dense than air, will offer a resistance 800 times greater to a given motion. Of the two mills represented in *Fig.* 36, that which goes with its edge first runs far longer than that which moves with its plane first. We are not, however, to understand that the effect of the medium, on a body moving through it, increases directly as the transverse section of the body; for a great deal depends upon its figure. A wedge, going with its edge first, will pass through water more easily than if impelled with its back first, though, in both instances, the area of the transverse section is of course the same. It is stated that spherical balls encounter one fourth less resistance from the air than would cylinders of equal diameter; and it is upon this principle that the bodies of fishes and birds are shaped, to enable them to move with as little resistance as may be through the media they inhabit.

The resistance of a medium increases with the velocity with which a body moves through it, being as the square of the velocity, so long as the motion is not too rapid; but when a high velocity is reached, other causes come into operation, and disturb the result.

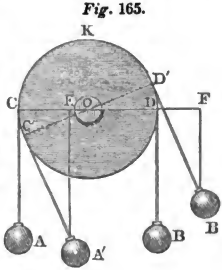
Describe the guinea and feather experiment. What does it prove? What is the cause of the stoppage of a pendulum? How does the density of a liquid affect its resistance? How is resistance affected by figure? How by velocity?

As with friction, so with the resistance of media, a great many results depend on this impediment to motion; among such may be mentioned the swimming of fish through water, and the flight of birds through the air. It is the resistance of the air which makes the parachute descend with moderate velocity downward, and causes the rocket to rise swiftly upward.

RIGIDITY OF CORDAGE.

In the action of pulleys, in machinery in which the use of cordage is involved, the rigidity of that cordage is an impediment to motion. When a cord acts round a pulley, in consequence of imperfect flexibility, it obtains a leverage on the pulley, as may be understood from *Fig.* 165, in which let C K D be the pulley working on a pivot at O; let A and B be weights suspended by the rope A C K D B. From what has been said respecting the theory of the pulley, the action of the machine may be regarded as that of a lever, C O D, with equal arms, C O, O D. Now, if the cord were perfectly *inflexible*, on making the weight A descend by the addition of a small weight to it, it would take the position at A′, the rope being a tangent to the pulley at C′; at the same time B, ascending, would take the position B′, its cord being a tangent at D′. From the new positions, A′ and B′, which the inflexible cord is thus supposed to have assumed, draw the perpendiculars, A′ E, B′ F., then will O E, O F, represent the arms of the lever on which they act—a diminished leverage on the side of the descending, and an increased leverage on the side of the ascending weight is the result.

Fig. 165.



In practice the result does not entirely conform to the foregoing imaginary case, because cords are, to a certain extent, flexible. As their pliability diminishes, the disturbing effect is greater. The degree of inflexibility de-

Mention some of the valuable results which depend on it. Give a general idea of the action of rigidity of cordage What takes place in case of absolute inflexibility, as in *Fig.* 165? On what does inflexibility depend?

pends on many casual circumstances, such as dampness or dryness, or the nature of the substance of which they are made. Inflexibility increases with the diameter of a cord, and with the smallness of the pulley over which it runs.

OF UNDULATORY MOTIONS.

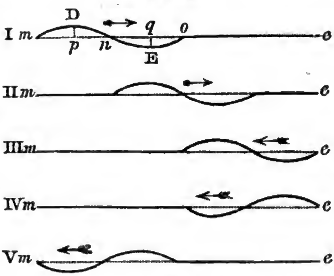
LECTURE XXXI.

OF UNDULATIONS.—*Origin of Undulations.—Progressive and stationary Undulation.—Course of a progressive Wave.—Nodal Points.—Three different kinds of Vibration.—Transverse Vibration of a Cord.—Vibrations of Rods.—Vibrations of elastic Planes.—Vibrations of Liquids.—Waves on Water.*

WHEN an elastic body is disturbed at any point, its particles gradually return to a position of rest, after executing a series of vibratory movements. Thus, when a glass tumbler is struck by a hard body, a tremulous motion is communicated to its mass, which gradually declines in force until the movement finally ceases.

In the same manner a stretched cord, which is drawn aside at one point, and then suffered to go, is thrown into a vibratory or undulatory movement; and, according as circumstances differ, two different kinds of undulation may be established, 1st, progressive undulations; 2d, stationary undulations.

Fig. 166.



In progressive undulations the vibrating particles of a body communicate their motion to the adjacent particles; a successive propagation of movement, therefore, ensues. Thus, if a cord is fastened at one end, and the other is moved up and down, a wave or undulation, *m* D *n* E *o*, is produced. The part, *m* D *n*, is the elevation

Under what circumstances do vibratory movements arise? How many kinds of undulations are there? Describe the nature of a progressive undulation.

of the wave, D being the summit, n E o is the depression, E being the lowest point, D p is the height, q E the depth, and m o the length of the wave.

But, under the circumstances here considered, the moment this wave has formed, it passes onward, and successively assumes the positions indicated at I, II, III. When it has arrived at the other end of the cord, it at once returns with an inverted motion, as shown at IV and V. This, therefore, is a progressive undulation.

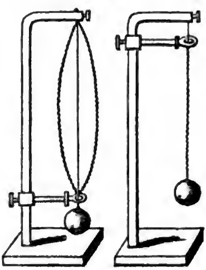
Again, instead of the cord receiving one impulse, let it be agitated equally at equal intervals of time; it will then divide itself, as shown in *Fig.* 167, into equal elevations and depressions with intervening points, m n, which are at rest. These are stationary undulations, and the points are called nodal points.

Fig. 167.

The agents by which undulatory movements are established are chiefly elasticity and gravity. It is the elasticity of air which enables it to transmit the vibratory motions which constitute sound, and, for the same reason, steel rods and plates of glass may be thrown into musical vibrations. In the case of threads and wires, a sufficient degree of elasticity may be given by forcibly stretching them. Waves on the surface of liquids are produced by the agency of gravity.

There are three different kinds of vibrations into which a stretched string may be thrown: transverse, longitudinal, and twisted. These may be illustrated by the instrument represented at *Fig.* 168. It consists of a piece of spirally-twisted wire, stretched from a frame by a weight. If the lower end of the wire be secured by a clamp, on pulling the wire in the middle, and then letting it go, it executes transverse vibrations. If the weight be gently lifted, and then let fall, the wire performs longitudinal vibrations; and if

Fig. 168.

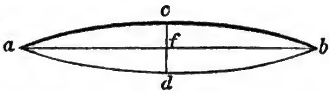


What is meant by the height, depth, and length of a wave? Describe the stationary vibration. By what agents are undulatory motions established? How may elasticity be communicated to cords? Into how many kinds of vibration may a string be thrown? How may this be illustrated by the apparatus represented in *Fig.* 168?

the weight be twisted round, and then released, we have rotatory vibrations.

If we take a string, *a b*, *Fig.*169, and having stretched it between two fixed points, *a* and *b*, draw it aside, and then let it go, it executes transverse vibrations, as has already been described. The cause of its motion, from the position we have stretched it to, is its own elasticity. This makes it return from the position, *a c b*, to the straight line, *a f b*, with a continually accelerated velocity; but when it has arrived in *a f b*, it cannot stop there, its momentum carrying it forward to *a d b*, with a velocity continually decreasing. Arrived in this position, it is, for a moment, at rest; but its elasticity again impels it as before, but in the reverse direction to *a f b;* and so it executes vibrations on each side of that straight line until it is finally brought to rest by the resistance of the air. One complete movement, from *a c b* to *a d b* and back, is called a vibration, and the time occupied in performing it the time of an oscillation.

Fig. 169.



The vibratory movements of such a solid are isochronous, or performed in equal lines. They increase in rapidity with the tension—that is, with the elasticity—being as the square root of that force. The number of vibrations in a given time is inversely as the length of the string, and also inversely as its diameter.

The vibrations of solid bodies may be studied best under the divisions of cords, rods, planes, and masses. The laws of the vibrations of the first are such as we have just explained.

In rods the transverse vibrations are isochronous, and in a given time are in number inversely as the squares of the lengths of the vibrating parts. Thus, if a rod makes two vibrations in one second, if its length be reduced to half it will make four times as many—that is, eight; if to one fourth, sixteen times as many—that is, thirty-two, &c. The motion performed by vibrating-rods is often very com-

Describe the transverse vibration of a string. What is a vibration? What is the time of an oscillation? What is meant by isochronous vibrations? How are the vibrations of solid bodies divided? What are the laws for the vibrations of rods?

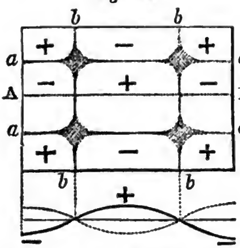
Fig 170.

plex. Thus, if a bead be fastened on the free extremity of a vibrating steel rod, *Fig.* 170, it will exhibit in its motions a curved path, as is seen at *c.* Rods may be made to exhibit nodal points. The space between the free extremity and the first nodal point is equal to half the length contained between any two nodal points, but it vibrates with the same velocity. Thus, *a*, *Fig.* 171, being the fixed, and *b* the free end of such a rod, the part between *b* and *c* is half the distance, *c c′*.

Fig. 171.

When elastic planes vibrate they exhibit *nodal lines*, answering to the nodal points in linear vibrations; and if the plane were supposed to be made up of a series of rods, these lines would answer to their nodal points. By them the plane is divided into spaces—the adjacent ones being always in opposite phases of vibrations, as shown by the signs + and — in *Fig.* 172, where A B is the vibrating plane. The dimensions of these spaces are regulated in the same way as the internodes of vibrating-rods—that is, the outside ones, *a b a b*, are always half the size of the interior. The relation of these spaces, and positions of the nodal lines may be determined by making a glass plate covered with dry sand vibrate.

Fig. 172.



When the surface of a liquid, as water, is touched, a wave arises at the disturbed point, and propagates itself into the unmoved spaces around, continually enlarging as it goes, and forming a progressive undulation.

A number of familiar facts prove that the apparent advancing motion of the liquid on which waves are passing is only a deception. Light pieces of wood are not hurried forward on the surface of water, but merely rise up and sink down alternately as the waves pass. The true

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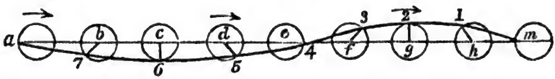
What are they for elastic planes? How may the nodal lines be made visible in the latter case? How are waves on liquid surfaces formed? Under such circumstances does the liquid actually advance, or is it stationary?

nature of the motion is such that each particle, at the surface of the undulating liquid, describes a circle in a vertical plane, and in the direction in which the wave is advancing, the movement being propagated from each to its next neighbor, and so on. And as a certain time must elapse for this transmission of motion, the different particles will be describing different points of their circular movement at the same moment. Some will be at the highest part of their vertical circle when others are in an intermediate position, and others at the lowest, giving rise to a wave, which advances a distance equal to its own length, while each particle performs one entire revolution. Thus, in *Fig.* 173, let there be eight particles of

Fig. 173.



water on the surface, *a m*, which, by some appropriate disturbance, are made to describe the vertical circles represented at *a b c d e f g h*, moving in the direction represented by the darts, and let each one of these commence its motion one eighth of a revolution later than the one before it. Then, at any given moment, when the first one, *a*, is in the position marked *a*, the second, *b*, will be in the position marked 7, *c* at 6, *d* at 5, *e* at 4, *f* at 3, *g* at 2, *h* at 1; but *m* will not yet have begun to move. If, therefore, we connect these various points, *a* 7 6 5 4 3 2 1 *m*, together by a line, that line will be on the surface of the wave, the length of which is *a m*, the height or depth of which is equal to the radius of the circle of each particle's revolution, and the time of passage through the length of one wave will be equal to the time of the revolution of each particle.

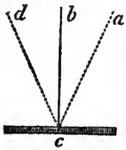
What is the true nature of the motion? Describe the illustration, *Fig.* 173.

LECTURE XXXII.

UNDULATIONS (continued).—*Law of the Reflection of Undulations.—Applied in the case of a Plane, a Circle, an Ellipse, a Parabola.—Case of a Circular Wave on a Plane.—Interference of Waves.—Inflexion of Waves.—Intensity of Waves.—Method of Combining Systems of Waves.*

BY a ray of undulation we mean a line drawn from the origin of a wave in the direction in which any given point of it is advancing. A wave is said to be incident when it falls on some resisting surface, and reflected when it recoils from it. Incident rays are those drawn from the origin toward the resisting surface, and reflected rays those expressing the path of the undulating points after their recoil. The angle of incidence is the angle which an incident wave makes with a perpendicular drawn to the surface of impact; the angle of reflexion is the angle made by the reflected ray and the same perpendicular. Thus, let *c* be a resisting surface of any kind, *a c* an incident ray, *c b* a perpendicular to the point of impact of the wave, *c d* the reflected ray. Then *a c b* is the angle of incidence, and *d c b* the angle of reflexion.

Fig. 174.



The general law for the reflexion of waves is, that "all the points in a wave will be reflected from the surface of the solid under the same angle at which they struck it."

If, therefore, parallel rays fall on a plane surface, they will be reflected parallel; if diverging, they will be reflected diverging; and if converging, converging.

If a circular wave advances from the center of a circular vessel, each ray falls perpendicularly on the surface of the vessel, and is reflected perpendicularly—that is to say, back in the line along which it came. The waves,

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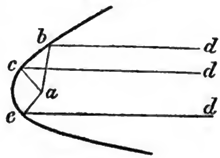
What is meant by a ray of undulation? What by incident and reflected rays? What is the angle of incidence, and what that of reflexion? What is the law of reflexion? How does this apply in the case of plane surfaces? What is the path of circular waves advancing from the center of a circular vessel after reflexion?

therefore, all return to the center from which they originated.

If undulations proceed from one focus of an ellipse, they will, after reflection, converge to the other focus.

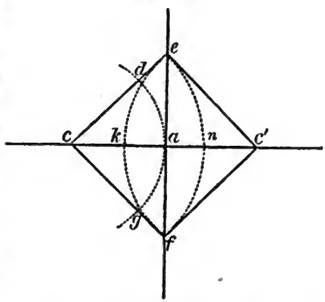
If a surface be a parabola, rays diverging from its focal point, *a*, will, after reflexion, pass in parallel lines, *b d*, *c d*, *e d*. Or if the rays impinge in parallel lines, they will, after reflexion, converge to the focus.

Fig. 175.



When diverging rays of a circular wave fall upon a plane surface, their path, after reflexion is such as it would have been had they originated from a point on the opposite side of the plane, and as far distant as the point of origin itself. Thus, let *c* be the origin of a circular wave, *d a g*, which impinges on a plane, *e f*, after reflexion this wave will be found at *e k f*, as though it had originated at *c′*, a point on the opposite side of *e f*, as far as *c*, in front of it. Now, the parts of the circular wave, *d a g*, do not all impinge on the plane at the same time, but that at *a*, which falls perpendicularly, impinges first, and is first reflected; the ray at *d* has to go still through the distance, *d e*, before reflexion takes place; but, in this space of time, the ray at *a* will have returned back to *k*; and, in the same way, it may be shown that the intermediate rays will have returned to intermediate positions, and be found in the line *e k f*, symmetrically situated, with respect to the line *e n f*, in which they would have been had they not fallen on the plane. And it further follows that the center, *c′*, of the circular wave, *e k f*, is as far from *e f* as is the centre, *c*, of the circular wave, *e n f*, but on the opposite side.

Fig. 176.



How are rays reflected that come from one of the foci of an ellipse? How is it in the case of a parabola. What is the principle illustrated in *Fig.* 176?

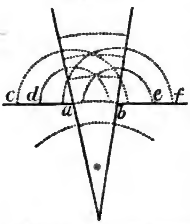
By interference we mean that two or more waves have encountered one another, under such circumstances as to destroy each other's effect. If on water two elevations or two depressions coincide, they conspire; but when an elevation coincides with a depression, interference takes place, and the surface of the fluid remains plane. Waves which have thus crossed one another continue their motion unimpaired.

If two systems of waves of the same length encounter each other, after having come through paths of *equal* length, they will not interfere; nor will they interfere, even though there be a difference in the length of their paths, provided that difference be equal to one whole wave, or two, or three, &c.

But if two systems of waves of equal length encounter each other after having come through paths of *unequal* length, they will interfere, and that interference will be complete when the difference of the paths through which they have come is half a wave, or one and a half, two and a half, three and a half, &c.

When a circular wave impinges on a solid in which there is an opening, as at *a*, *b*, *Fig.* 177, the wave passes through, and is propagated to the spaces beyond; but other waves arise from *a b*, as centers, and are propagated as represented at *c d e f*. This is the *inflexion* of waves, and these new waves intersecting one another and the primitive one, give rise to interferences.

Fig. 177.



We have now traced the chief phenomena of vibrations in solids and on the surface of liquids. It remains to do the same for elastic bodies, such as gases.

When any vibratory movement takes place in atmospheric air, the impulse communicated to the particles causes them to recede a certain distance, condensing those that are before them; the impulse is finally overcome by the resistance arising from this condensation. There,

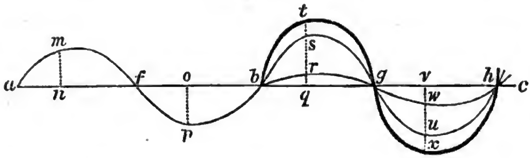
What is meant by the interference of waves? When will two systems of waves *not* interfere? When will they interfere? What is meant by the inflexion of waves? What are the phenomena of vibrations in elastic media, as atmospheric air?

therefore, arises a sphere of air, the superficies or shell of which has a maximum density. Reaction now sets in, the sphere contracts, and the returning particles come to their original positions. But as a disturbance on the surface of a liquid gives origin to a progressive wave, so does the same thing take place in the air.

By the intensity of vibration of a wave we mean the relative disturbance of its moving particles, or the magnitude of the excursions they make on each side of their line of rest. Thus, on the surface of water we may have waves "mountains high," or less than an inch high; the intensity of vibration in the former is correspondingly greater than in the latter case.

In aerial waves, precisely as in the surface-waves of water, interference arises under the proper conditions. Thus, let *a m p h*, *Fig.* 178, be a wave advancing toward

Fig. 178.



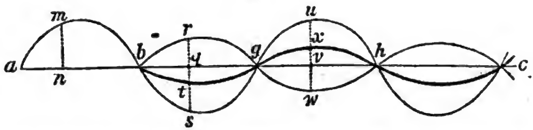
c, and let *m n*, *o p* be the *intensity of its vibration*, or the maximum distances of the excursions of its vibrating particles. Then suppose a second wave, originating at *b* (a distance from *a* precisely equal to one wave length), the intensity of vibration of which is represented by *q r*. The motions of this second wave coinciding throughout its length with the motions of the first, the force of both systems is increased. The intensity, therefore, of the wave, arising from their conjoint action at any point, *q* will be equal to the sum of their intensities, *q r*, *q s*—that is, it will be *q t*, and for any other point, *v*, it will be equal to the sum of *v w* and *v u*—that is, *v x*. So the new wave will be represented by *b t g x h*.

Now let things remain as before, except that the point of impact of the second wave, instead of being one whole wave from *a*, is only half a wave, the effects on any parti-

What is meant by the intensity of vibration? Trace the phenomena of interference represented in *Figs*. 178 and 179 respectively.

cle, such as *q*, take place in opposite directions, the second wave moving it with the intensity and direction *q*

Fig. 179.



r, the first with *q s*—the resultant of its movement in intensity and direction, will, therefore, be the difference of these quantities—that is, *q t*. And the same reasoning continued gives, for the wave resulting from this conjoint action, *b t g x h c*.

Under the circumstances given in *Fig*. 178, the systems of waves increase each other's force; under those of *Fig*. 179, they diminish it; or if equal to one another counteract completely, and total interference results.

Waves in the air, as they expand, have their superficies continually increasing, as the squares of their radii of distance from the original point of disturbance. Hence the effect of all such waves is to diminish as the squares of the distances increase.

Under what law does the effect of waves in the air diminish?

THE LAWS OF SOUND.

ACOUSTICS.

LECTURE XXXIII.

PRODUCTION OF SOUND.—*The Note Depends on Frequency of Vibration.—Distinguishing Powers of the Ear.—Soniferous Media.—Origin of Sounds in the Air.—Elasticity Required and Given in the Case of Strings by Stretching.—Rate of Velocity of Sounds.—All Sounds Transmitted with Equal Speed.—Distances Determined by it.—High and Low Sounds.—Three Directions of Vibration.—Intensity of Sound.—Quality of Sounds.—The Diatonic Scale.*

WHEN a thin elastic plate is made to vibrate, one of its ends being held firm and the other being free, and its length limited to a few inches, it emits a clear musical note. If it be gradually lengthened, it yields notes of different characters, and finally all sound ceases, the vibrations becoming so slow that the eye can follow them without difficulty.

This instructive experiment gives us a clear insight into the nature of musical sounds, and, indeed, of all sounds generally. A substance which is executing a vibratory movement, provided the vibrations follow one another with sufficient rapidity, yields a musical sound; but when those vibrations fall below a certain rate, the ear can no longer distinguish the effect of their impulsions.

The number of vibrations which such a plate makes in

What is the nature of a musical sound? Under what circumstances does the sound become inaudible? What regulates the number of vibrations of an elastic plate?

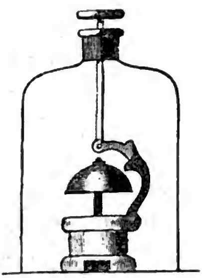
a given time depends upon its length, being inversely as the square of the length of the vibrating part. Thus, if we take a given plate and reduce its length, the vibrations will increase in rapidity; when it is half as long it vibrates four times as fast; when one fourth, sixteen times, &c.

All sounds arise in vibratory movements, and musical notes differ from one another in the rapidity of their vibrations—the more rapidly recurring or frequent the vibration the higher the note.

There is, therefore, no difficulty in determining how many vibrations are required to produce any given note. We have merely to find the length of a plate which will yield the note in question, knowing previously what length of it is required to make a determinate number of vibrations in a given space of time. Thus it has been found that the ear can distinguish a sound made by 15 vibrations in a second, and can still continue to hear though the number reaches 48,000 per second.

That all sounds arise in these pulsatory movements common observations abundantly prove. If we touch a bell, or the string of a piano, or the prong of a tuning-fork, we feel at once the vibratory action, and with the cessation of that motion the sound dies away.

Fig. 180.



But the pulsations of such a body are not alone sufficient to produce the phenomena of sound. Media must intervene between them and the organ of hearing. In most cases the medium is atmospheric air, and when this is taken away the effect of the vibrations wholly ceases. Thus, a bell or a musical snuff-box, under an exhausted receiver, as in *Fig.* 180, can no longer be heard; but on readmitting the air the sound becomes audible. The sounding body, therefore, requires a soniferous medium to propagate its impulses to the ear.

Atmospheric air is far from being the only soniferous

How may the number of vibrations which constitute any sound be determined? How may it be proved that all sounds arise in vibratory movements? How may it be proved that a soniferous medium is required?

medium. Sounds pass with facility through water; the scratching of a pin or the ticking of a watch may be heard by the ear applied at the end of a very long plank of wood. Any uniform elastic medium is capable of transmitting sound; but bodies which are imperfectly elastic, or have not an uniform density, impair its passage to a corresponding degree.

The effect of a vibrating spring, or, indeed, of any vibrating body on the atmospheric air, is to establish in it a series of condensations and rarefactions which give rise to waves. These, extending spherically from the point of disturbance, advance forward until they impinge on the ear, the structure of which is so arranged that the movement is impressed on the auditory nerves, and gives rise to the sensation which we term sound.

Both the sonorous body and the soniferous medium must, therefore, be elastic, the regularity of the pulsations of the former depends upon the uniformity of its elasticity. In the case of strings, we give them the requisite degree of elastic force by stretching them to the proper degree. And, as the undulatory movements which arise in the soniferous medium are not instantaneous, but successive, it follows that the transmission of sound in any medium requires time. That this is the case, we may satisfy ourselves by remarking the period that elapses between seeing the flash of a gun and hearing the report. It is greater as we are removed to a greater distance. In different media, the velocity of transmission depends on the density and specific elasticity. It has been found, by experiment, that in tranquil air the velocity of sound at 60°, and at an average state of moisture, is 1120 feet in a second. The wind accelerates or retards sound, according to its direction, damp air transmits it more slowly than dry, and hot air more rapidly than cold, the velocity increasing about 1·1 foot for every Fahrenheit degree.

In a soniferous medium, all sounds move equally fast; it is wholly immaterial what may be their quality or their

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Mention some such soniferous media. How is it that sounds are finally perceived by the ear? What condition is required both for the sounding body and soniferous medium? How may sufficient elasticity be given in the case of strings? Does the transmission of sound require time? What is the velocity of sound per second? What is the effect of the wind, dampness, or change of temperature?

intensity. Thus, we know that even the most intricate music executed at a distance is heard without any discord, and precisely as it would be close at hand. Nor does it matter whether it be by the human voice, a flute, a bugle, or, indeed, by many different instruments at once, the relation of the difference of sounds is accurately preserved. But this can only take place as a consequence of the equal velocity of transmission; for if some of these sounds moved faster than others discord must inevitably ensue.

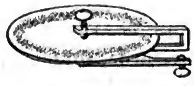
The experiments of Colladon and Sturm on the Lake of Geneva show that the velocity in water is about four times that in air, being 4708 feet in a second. With respect to solid substances, it is stated that the velocity in air being 1, that in tin is 7½, in copper 12, in glass 17.

Advantage is sometimes taken of these principles to determine distances. If we observe the time elapsing between the flash of a gun and hearing the sound, or between seeing lightning and hearing the thunder, every second answers to 1120 feet.

Sounds are of different kinds: some are low or high, grave or acute, according as the vibrations are slower or faster. Again: the intensity of vibration or the magnitudes of the excursions which the vibrating particles make determine the force of sounds, an intense vibration giving a loud, and a less vibration a feeble sound.

The vibrations of a soniferous body may take place in three directions: they may be longitudinal, transverse, or rotatory vibrations; or, indeed, they may all co-exist.

Fig. 181.



A body may be divided into vibrating parts, separated from one another by nodal points or lines. Thus, if we take a glass or metal plate, and having strewed its surface with fine dry sand, and holding it firmly at one point between the thumb and finger, or in a clamp, as represented in *Fig.* 181, draw a violin bow across its edge, it yields a musical note, and the sand is thrown off those places which are in motion, and collects on the nodal points, which are at rest.

The *quantity*, or *strength*, or *intensity* of a sound de

What is the velocity of sounds in water? Into what varieties may sound be divided? In what directions may a sounding body vibrate? How may nodal lines on surfaces be traced?

pends on the intensity of the vibrations and the mass of the sounding body. It also varies with the distance, being inversely proportional to its square.

Musical sounds are spoken of as notes, or as *high* and *low*. Of two notes, the higher is that which arises from more rapid, and the lower from slower vibrations.

Besides this, sounds differ in their quality. The same note emitted by a flute, a violin, a piano, or the human voice is wholly different, and in each instance peculiar. In what this peculiarity consists we are not able to say.

The several notes are distinguished by letters and names; we shall also see presently that they may be distinguished by numbers. They are—

C D E F G A B C.
Or, ut, re, mi, fa, sol, la, si, ut.

Such a series of sounds passes under the name of the diatonic scale.

LECTURE XXXIV.

PHENOMENA OF SOUND.—*Notes in Unison.—Octave.—Interval of Sounds.— Melody.— Harmony.— The Monochord.—Length of Cord and Number of Vibrations required for each Note.—Laws of Vibrations in Cords, Rods, Planes.—Acoustic Figures on Plates.—Vibration of Columns of Air.—Interference of Sounds.—Whispering Galleries.—Echoes.—Speaking and Hearing-Trumpet.*

Two notes are said to be in *unison* when the vibrations which cause them are performed in equal times. If the one makes twice as many vibrations as the other, it is said to be its *octave*, and the *relation* or *interval* there is between two sounds is the proportion between their respective numbers of vibrations.

There are combinations of sounds which impress our organs of sense in an agreeable manner, and others which

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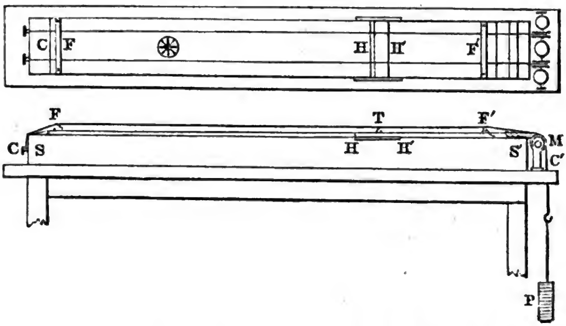
On what does the intensity of sound depend? What is it that determines the highness or lowness of notes? What is meant by the quality of sounds? How may notes be distinguished? When are notes in unison? What is an octave? What is the relation or interval of sounds?

produce a disagreeable effect. In this sense, we speak of the former as being in unison, and the latter as being discordant. A combination of harmonious sounds is *a chord*, a succession of harmonious notes a melody, and a succession of chords harmony.

We have remarked in the last lecture that sounds may be expressed by numbers as well as by letters or names, and their relations to one another clearly exhibited. For this purpose, we may take the monochord or sonometer, C C′, *Fig.* 182, an instrument consisting of a wire or

Fig. 182.



catgut stretched over two bridges, F F′, which are fastened on a basis, S S′; one end of the cord passes over a pulley, M, and may be strained to any required degree of weights, P. The length of the string vibrating may be changed by pressing it with the finger upon a movable piece, H, which carries an edge, T, and the case beneath is divided into parts which exhibit the length of the vibrating part of the wire. The upper part of *Fig.* 182 shows a horizontal view of the monochord, the lower a lateral view. The instrument here represented has two strings, one of catgut and one of wire.

Now, it is to be understood that the number of vibrations of such a cord are inversely as its length; that is, if the whole cord makes a given number of vibrations in one second, when you reduce its length to one half it will make twice as many; if to one third, thrice as many, &c.

What is a chord, a melody, and harmony? Describe the monochord.

Suppose the cord is stretched so as to give a clear sound, which we may designate as C, and the movable bridge is then advanced so as to obtain successively the other notes of the gamut, D, E, F, G, A, B, C, it will be found that these are given when the lengths of the cord, compared with its original length, are—

Name of note . . .	C	D	E	F	G	A	B	C
Length of cord . . .	1,	$\frac{8}{9}$,	$\frac{4}{5}$,	$\frac{3}{4}$,	$\frac{2}{3}$,	$\frac{3}{5}$,	$\frac{8}{15}$,	$\frac{1}{2}$.

but as the number of vibrations is in the inverse ratio of the lengths of the vibrating cords, we shall have for the number of vibrations, if we represent by 1, the number that gives C, the following for the other notes:

Name of note . . .	C	D	E	F	G	A	B	C
Number of vibrations . .	1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{15}{8}$	2.

From C to C is an octave, and from this we gather that, in the octave, the higher note makes twice as many vibrations as the fundamental note, and that between these there are other intervals, which, heard in succession, are harmonious; the eight, therefore, constitute a scale, commonly called the diatonic scale.

Musical instruments are of different kinds, depending on the vibrations of cords, rods, planes, or columns of air.

It has already been stated, that the number of vibrations of a cord is inversely as its length—the number also increases as the square root of the force that stretches it; thus, the octave is given by the same string when stretched four times as strongly; the material of the string, whether it be catgut, iron, &c., also affects the note.

In rods the height of the note is directly as the thickness, and inversely as the square of the length. The quality of the material also, in respect of elasticity, determines the note.

The foregoing observations apply to transverse vibrations of cords and rods; but they may be also made to execute longitudinal and torsion vibrations, the conditions of which are different.

In planes held by one point, and a bow drawn across at another, or struck by a blow, sounds are emitted, and by the aid of sand nodal lines may be traced. Thus, in *Fig.* 183, *a* is the point, in each instance, at which the

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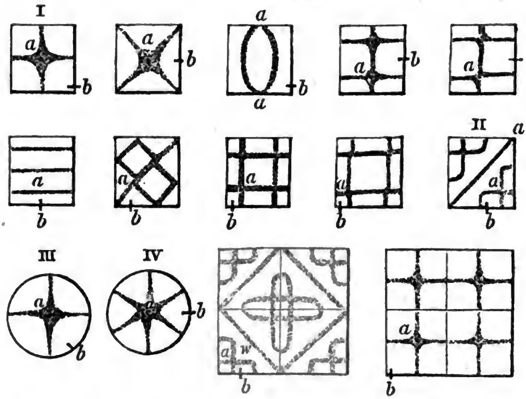
What lengths of a cord are required to give the notes of the gamut? What are the corresponding number of vibrations? What is the diatonic scale? What are the laws for the vibration of cords? What in the case of rods?

plate is held, and *b* that at which the bow is applied; the sand arranges itself in the dotted lines.

The two large figures are formed by putting together four smaller plates, in one instance bearing the nodal lines, represented at I, and, in the other, at II. They may, however, be directly generated on one large plate of glass by holding it at *a*, touching it at *w*, and drawing the bow across it at *b*.

Fig. 183.



Circular plates, *a* in III, may be made to bear a four-rayed star, by holding them in the center, drawing the bow at any point at *b*, and touching the plate at a point 45° distant from the bow; but if the plate be touched 30°, 60°, or 90° off, it produces a six-rayed star, *Fig.* IV.

Columns of air may be made to emit sounds by being thrown into oscillation, as in horns, flutes, clarionets, &c. In these the column of air, included in the tube of the instrument, is made to vibrate longitudinally. The height of the note is inversely proportional to the length of the column, and therefore different notes may be obtained by having apertures, at suitable distances, in the side of the tube, as in the flute.

Two sounds may be so combined together that they shall

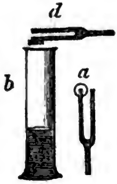
In the case of planes how may the nodal lines be varied? How may columns of air be made to vibrate? How is the length of the vibrating column varied in different wind instruments?

mutually destroy each other's effect, and silence result. This arises from interference taking place in the aerial waves, the laws of which are those given in Lecture XXXII. The following instances will illustrate these facts.

When a tuning-fork is made to vibrate, and is turned round upon its axis near the ear, four periods may be discovered during every revolution in which the sound increases or declines.

If we take two tuning-forks of the same note, *a d*, *Fig.* 184, and fasten a circle of cardboard, half an inch in diameter, on one of the prongs of each, and make one of the forks a little heavier than the other, by putting on it a drop of wax, and then filling a jar, *b*, to such a height with water, that either of the forks, when held over it, will make it resound, so long as only one is held, there will be a continuous note, without pause or interruption; but if both are held together, there will be periods of silence and periods of sound, according as the longer waves, arising from one of the forks, overtakes and interferes with the shorter waves, arising from the other.

Fig. 184.



Sounds undergo reflexion, and may therefore be directed by surfaces of suitable figure. If, in the focus of a concave mirror a watch be placed, its ticking may be heard at a great distance in the focus of a second mirror, placed so as to receive the sound-waves of the first.

On similar principles also whispering-galleries depend. These are so constructed that a low whisper uttered at one point is reflected to a focus at another, in which it may be distinctly heard, while it is inaudible in other positions. The dome of St. Paul's cathedral, in London, is an example.

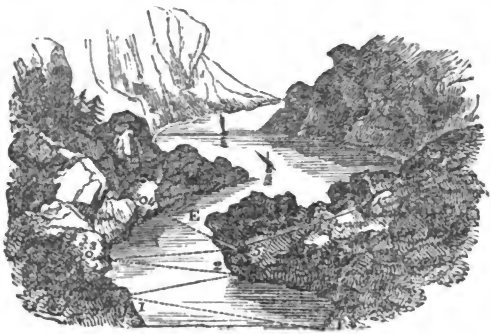
Echoes are reflected sounds. Thus, if a person stands in front of a vertical wall, and at a distance from it of about 62½ feet, if he utters a syllable, he will hear a sound which is the echo of it. If there be a series of such vertical obstacles, at suitable distances, the same sound may be repeated many successive times. A good ear can distinguish nine distinct sounds in a second; and, as a sound

Give some illustrations of the interference of sound. How may it be proved that sounds undergo reflexion? What are whispering-galleries? Under what circumstances do echoes arise?

travels 1120 feet in the same time, for the echo to be clearly distinguished from its original sound, it must travel 125 feet in passing to and from the reflecting surface, that is, the reflector must be at least 62½ feet distant.

Remarkable echoes exist in several places. One near Milan repeats a sound thirty times. The ancients mention one which could repeat the first verse of the Æneid

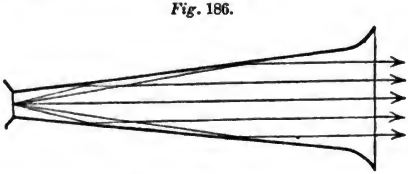
Fig. 185.



eight times. On the banks of rivers—as, for example, on the Rhine, as represented in *Fig.* 185—sounds are often echoed from the rocks, rebounding, as at 1, 2, 3, 4, from side to side.

Speaking-trumpets depend on the reflection of sound. The divergence is prevented by the sides of its tube; and if the instrument is of a suitable figure, the rays of sound issue from it, as seen in *Fig.* 186, in a parallel direction. Its efficiency depends on its length. It is stated that through such an instrument, from 18 to 24 feet long, a man's voice can be heard at a distance of three miles. Under common circumstances, the greatest distances at which sounds have

Fig. 186.

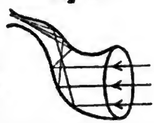


Why must two reflecting surfaces be at a certain distance? What is the construction of the speaking-trumpet?

been heard are usually estimated as follows: the report of a musket, 8000 paces; the march of a company of soldiers at night, 830 paces; a squadron galloping, 1080; the voice of a strong man, in the open air, 230. But the explosions of the volcano of St. Vincent were heard at Demerara, 345 miles; and, at the siege of Antwerp, the cannonading was heard, in the mines of Saxony, 370 miles.

The hearing-trumpet is for the purpose of collecting rays of sound by reflexion, and transmitting them to the ear. Its mode of action is represented at *Fig.* 187.

Fig. 187.



At what distance can sounds be heard? What is the construction of the hearing-trumpet.

PROPERTIES OF LIGHT.

OPTICS.

LECTURE XXXV.

Properties of Light.—*Theories of the Nature of Light.—Sources of Light.—Phosphorescence.—Temperature of a red Heat.—Effects of Bodies on Light.—Passage in straight Lines.—Production of Shadows.—Umbra and Penumbra.*

Having successively treated of the general mechanical properties of gases, liquids, solids, and the laws of motion, we are led, in the next place, to the consideration of certain agents or forces—light, heat, electricity. These, by many philosophers, are believed to be matter, in an imponderable state; they are therefore spoken of as imponderable substances. By others their effects are regarded as arising from motions or modifications impressed on a medium everywhere present, which passes under the name of the ether.

Applying these views to the case of light, two different hypotheses, respecting its constitution, obtain. The first, which has the designation of the *theory of emission*, regards light as consisting of particles of amazing minuteness, which are projected by the shining body, in all directions, and in straight lines. These impinging eventually on the organ of vision, give rise to the sensation which we speak of as brightness or light. To the other theory, the title of *undulatory theory* is given; it supposes that there exists throughout the universe an ethereal medium, in which vibratory movements can arise somewhat analogous to the movements which give birth to sounds

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Name the imponderable substances. What other theory is there respecting their nature? What is the theory of emission? What is the foundation of the undulatory theory?

in the air; and these passing through the transparent parts of the eye, and falling on the retina, affect it with their pulsations, as waves in the air affect the auditory nerve, but in this case give rise to the sensation of light, as in the other to sound.

There are many different sources of light—some are astronomical and some terrestrial. Among the former may be mentioned the sun and the stars—among the latter, the burning of bodies, or combustion, to which we chiefly resort for our artificial lights, as lamps, candles, gas flames. Many bodies are phosphorescent, that is to say, emit light after they have been exposed to the sun or any shining source. Thus, oyster-shells, which have been calcined with sulphur, shine in a dark place after they have been exposed to the light, and certain diamonds do the same. So, too, during processes of putrefaction, or slow decay, light is very often emitted, as when wood is mouldering or meat is becoming putrescent. The source of the luminousness, in these cases, seems to be the same as in ordinary combustions, that is, the burning away of carbon and hydrogen under the influence of atmospheric air; but, in certain cases, the functions of life give rise to an abundant emission of light, as in fireflies and glowworms; these continue to shine even under the surface of water, and there is reason to believe that the phenomenon is to a considerable extent subject to the volition of the animal.

All solid substances, when they are exposed to a certain degree of heat, become incandescent or emit light. When first visible in a dark place, this light is of a reddish color, but as the temperature is carried higher and higher it becomes more brilliant, being next of a yellow, and lastly of a dazzling whiteness. For this reason we sometimes indicate the temperature of such bodies, in a rough way, by reference to the color they emit: thus we speak of a red heat, a yellow heat, a white heat. I have recently proved that all solid substances begin to emit light at the same degree of heat, and that this answers to $977°$ of Fahrenheit's thermometer; moreover, as the tem-

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Mention some of the sources of light. What is meant by phosphorescence? To what source may the light emitted during putrefaction and decay be attributed? What is there remarkable in the shining of glowworms and fireflies? What is meant by incandescence? What succession of colors is perceived in self-luminous bodies? At what temperature do all solids begin to shine?

perature rises the brilliancy of the light rapidly increases, so that at a temperature of 2600° it is almost forty times as intense as at 1900°. At these high temperatures an elevation of a few degrees makes a prodigious difference in the brilliancy. Gases require to be brought to a far higher temperature than solids before they begin to emit light.

Non-luminous bodies become visible by reflecting the light which falls on them. In their general relations such bodies may be spoken of as transparent and opaque. By the former we mean those which, like glass, afford a more or less ready passage to the light through them; by the latter, such as refuse it a passage. But transparency and opacity are never absolute—they are only relative. The purest glass extinguishes a certain amount of the rays which fall on it, and the metals which are commonly looked upon as being perfectly opaque allow light to pass through them, provided they are thin enough. Thus gold leaf spread upon glass transmits a greenish-colored light.

The rays of light, from whatever source they may come, move forward in straight lines, continuing their course until they are diverted from it by the interposition of some obstacle, or the agency of some force. That this rectilinear path is followed may be proved by a variety of facts. Thus, if we intervene an opaque body between any object and the eye, the moment the edge of that body comes to the line which connects the object and the eye the object is cut off from our view. In a room into which a sunbeam is admitted through a crevice, the path which the light takes, as is marked out by the motes that float in the air, is a straight line.

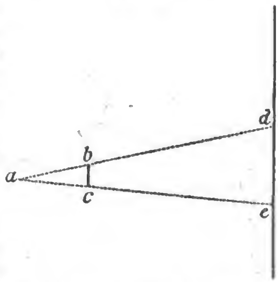
By a ray of light we mean a straight line drawn from the luminous body, marking out the path along which the shining particles pass.

A shining body is said to radiate its light, because it projects its luminous particles in straight lines, like radii, in every direction, and these falling on opaque bodies and being intercepted by them, give rise to the production of shadows.

At what rate does the light increase as the temperature rises? Are solids or gases most readily made incandescent? How do non-luminous bodies become visible? What classes are they divided into? Are transparency and opacity absolute qualities? Prove that rays move in straight lines. What is meant by radiation? How are shadows produced?

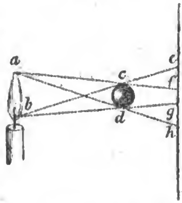
If the light is emitted by a single luminous point, the boundary of the shadow can be obtained by drawing straight lines from the luminous point to every point on the edge of the body, and producing them. Thus, let *a*, *Fig.* 188, be the luminous point, *b c* the opaque body; by drawing the lines *a b*, *a c*, and producing them to *d* and *e* the boundary and figure of the shadow may be exhibited.

Fig. 188.



But if the luminous body, as in most instances is the case, possesses a sensible magnitude; if it is, for example, the sun or a flame, an opaque body will cast two shadows, which pass respectively under the names of the *umbra* and *penumbra*—the former being dark and the latter partially illuminated. This may be illustrated by *Fig.* 189, in which *a b* is the flame of a candle or any other luminous source, having a sensible magnitude, *c d* the opaque body. Now the straight lines, *a c f*, *a d h*, drawn from the top of the flame to the edges of the opaque body and produced, give the shadow for that point of the flame; and the lines *b c e*, *b d g*, drawn in like manner from the bottom of the flame, give the shadow for that point. But we see that the space between *g* and *h*, which belongs to the shadow for the top of the flame, is not perfectly dark, because it is so situated as to be partially illuminated by the bottom of the flame—and a similar remark may be made as respects the space, *f e*, which receives light from the top of the flame. But the remaining space, *f g*, receives no light whatever—it is totally dark—and we therefore call it the *umbra*, while the partially-illuminated regions, *f e* and *g h*, are the *penumbra*.

Fig. 189



Trace the shadow of a body formed by a luminous point. Trace the formation of a shadow when the luminous source is of sensible size. What is the umbra? What is the penumbra?

LECTURE XXXVI.

OF THE MEASURES OF THE INTENSITY AND VELOCITY OF LIGHT.—*Conditions of the Intensity of Light.—Of Photometric Methods.—Rumford's Method by Shadows.—Ritchie's Photometer.—Difficulties in Colored Lights.—Masson's Method.— Velocity of Light Determined by the Eclipses of Jupiter's Satellites.—The same by the Aberration of the Fixed Stars.*

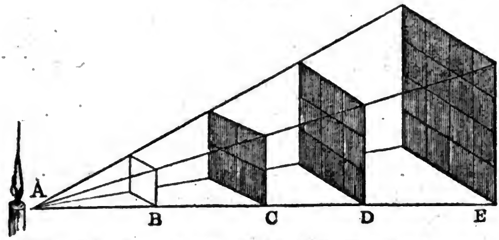
BY Photometry we mean the measurement of the brilliancy of light—an operation which can be conducted in many different ways.

It is to be understood that the illuminating power of a shining body depends on several circumstances: First, upon its distance—for near at hand the effect is much greater than far off—the law for the intensity of light in this respect being that the brilliancy of the light is inversely as the square of the distance. A candle two feet off gives only one fourth of the light that it does at one foot, at three feet it gives only one ninth, &c. Secondly, it depends on the absolute intensity of the luminous surface: thus we have seen that a solid at different degrees of heat emits very different amounts of light, and in the same way the flame of burning hydrogen is almost invisible, and that of spirits of wine is very dull when compared with an ordinary lamp. Thirdly, it depends on the area or surface the shining body exposes, the brightness being greater according as that surface is greater. Fourthly, in the absorption which the light suffers in passing the medium through which it has to traverse—for even the most transparent obstructs it to a certain extent. And lastly, on the angle at which the rays strike the surface they illuminate, being most effective when they fall perpendicularly, and less in proportion as their obliquity increases.

What is photometry? Mention some of the conditions which determine the brilliancy of light. What is the law of its decrease by distance? What has obliquity of surfaces to do with the result?

The first and last of the conditions here mentioned, as controlling the intensity of light—the effect of distance and of obliquity—may be illustrated as follows:—

Fig. 190.



1st. That the intensity of light is inversely as the squares of the distance. Let B, *Fig.* 190, be an aperture in a piece of paper, through which rays coming from a small illuminated point, A, pass; let these rays be received on a second piece of paper, C, placed twice as far from A as is B, it will be found that they illuminate a surface which is twice as long and twice as broad as A, and therefore contains four times the area. If the paper be placed at D, three times as far from A as is B, the illuminated space will be three times as long and three times as broad as A, and contain nine times the surface. If it be at E, which is four times the distance, the surface will be sixteen times as great. All this arises from the rectilinear paths which the diverging rays take, and therefore a surface illuminated by a given light will receive, at distances represented by the numbers 1, 2, 3, 4, &c., quantities of light represented by the numbers 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, &c., which latter are the inverse squares of the former numbers.

2d. That the intensity of light is dependent on the angle at which the rays strike the receiving surface, being most effective when they fall perpendicularly, and less in proportion as the obliquity increases. Let there be two surfaces, D C and E C, *Fig.* 191, on which a beam of light, A B, falls on the former perpendicularly and on the latter obliquely—the latter surface, in proportion to its obliquity, must have a larger area to receive *all* the rays which fall on D C. A given quantity of light, therefore,

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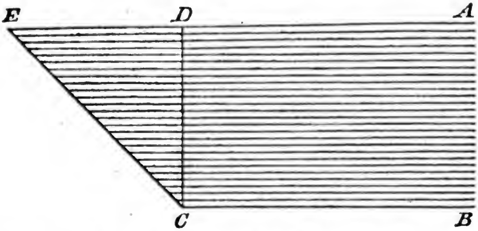
Give illustrations of the effect of distance and of obliquity.

Fig. 191.



is diffused over a greater surface when it is received obliquely, and its effect is correspondingly less.

To compare different lights with one another, Count Rumford invented a process which goes under the name of the method of shadows. The principle is very simple. Of two lights, that which is the most brilliant will cast the deepest shadow, and with any light the shadow which is cast becomes less dark as the light is more distant. If, therefore, we wish to examine experimentally the brilliancy of two lights on Rumford's method, we take a screen of white paper and setting in front of it an opaque rod, we place the lights in such a position that the two shadows arising shall be close together, side by side. Now the eye can, without any difficulty, determine which of the two is darkest; and by removing the light which has cast it to a greater distance, we can, by a few trials, bring the two shadows to precisely the same degree of depth. It remains then to measure the distances of the two lights from the screen, and the illuminating powers are as the squares of those distances.

Ritchie's photometer is an instrument for obtaining the same result, not, however, by the contrast of shadows, but by the equal illumination of surfaces. It consists of a box, *a b*, *Fig.* 192, six or eight inches long and one broad and deep, in the middle of which a wedge of wood, *f e g*, with its angle, *e*, upward, is placed. This wedge is covered over with clean white paper, neatly doubled to a sharp line at *e*. In the top of the box there is a conical tube, with an aperture, *d*, at its upper end, to which the

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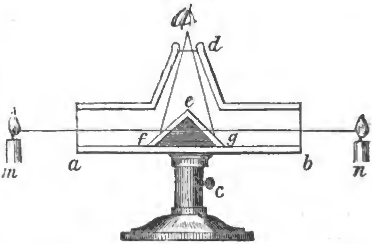
What is the principle of Rumford's photometric process? How is it applied in practice? What is the illuminating power of the lights proportional to? Describe Ritchie's photometer.

eye is applied, and the whole may be raised to any suitable height by means of the stand *c*. On looking down through *d*, having previously placed the two lights, *m n*, the intensity of which we desire to determine on opposite sides of the box, they illuminate the paper surfaces exposed to

Fig. 192.



them, *e f* to *m* and *e g* to *n*, and the eye, at *d*, sees both those surfaces at once. By changing the position of the lights, we eventually make them illuminate the surfaces equally, and then measuring their distances from *e*, their illuminating powers are as the squares of those distances.

It is not possible to apply either of these methods in a satisfactory manner where, as is unfortunately often the case, the lights to be examined differ in color. The eye can form no judgment whatever of the relation of brightness of two surfaces when they are of different colors; and a very slight amount of tint completely destroys the accuracy of these processes. To some extent, in Ritchie's instrument, this may be avoided, by placing a colored glass at the aperture, *d*.

A third photometric method has recently been introduced; it has great advantages over either of the foregoing; and difference of color, which in them is so serious an obstacle, serves in it actually to increase the accuracy of the result. The principle on which it is founded is as follows: If we take two lights, and cause one of them to throw the shadow of an opaque body upon a white screen, there is a certain distance to which, if we bring the second light, its rays, illuminating the screen, will totally obliterate all traces of the shadow. This disappearance of the shadow can be judged of with great

What difficulties arise when the lights and the shadows they give are colored? How may these be avoided? Describe another process which is free from the foregoing difficulties. On what principle does it depend?

accuracy by the eye. It has been found that eyes of average sensitiveness fail to distinguish the effect of a light when it is in presence of another sixty-four times as intense. The precise number varies somewhat with different eyes; but to the same eye it is always the same. If there be any doubt as to the perfect disappearance of the shadow, the receiving screen may be agitated or moved a little. This brings the shadow, to a certain extent, into view again. Its place can then be traced; and, on ceasing the motion, the disappearance verified.

When, therefore, we desire to discover the relative intensities of light, we have merely to inquire at what distance they effect the total obliteration of a shadow, and their intensities are as the squares of those distances. I have employed this method for the determination of the quantities of light emitted by a solid at different temperatures, and have found it very exact.

Light does not pass instantaneously from one point to another, but with a measurable velocity. The ancients believed that its transmission was instantaneous, illustrating it by the example of a stick, which, when pushed at one end, simultaneously moves at the other. They did not know that even their illustration was false; for a certain time elapses before the farther end of the stick moves; and, in reality, a longer time than light would require to pass over a distance equal to the length of the stick. But in 1676, a Danish astronomer, Roemer, found, from observations on the eclipses of Jupiter's satellites, that light moves at the rate of about 192,000 miles in one second.

This singular observation may be explained as follows: Let S, *Fig.* 193, be the sun, E the earth, moving in the orbit E E′, as indicated by the arrows; let J be Jupiter and T his first satellite, moving in its orbit round him. It takes the satellite 42 hours 28 minutes 35 seconds to pass from T to T′—that is to say, through the planet's shadow. But, during this period of time, the earth moves in her orbit, from E to E′, a space of 2,880,000 miles. Now, it is found, under these circum-

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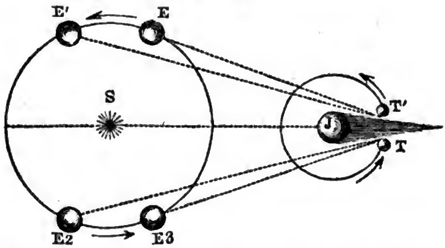
Does light move with instantaneous velocity? Who discovered its progressive motion? What is its actual rate? Describe the facts by which this has been determined. By whom and under what circumstances has this been verified?

stances, that the emersion of the satellite is 15 seconds

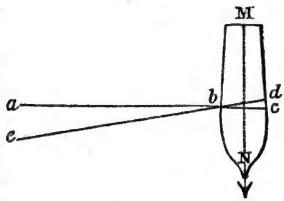
Fig. 193.



later than it should have been. And it is clear that this is owing to the fact that the light requires 15 seconds to pass from E to E′ and overtake the earth. Its velocity, therefore, in one second, must be 192,000 miles.

This beautiful deduction was corroborated by Dr. Bradley, in 1725, upon totally different principles, involving what is termed the aberration of the stars. The principle, which is somewhat difficult to explain, is clearly illustrated by Eisenlohr as follows: Let M N represent a ship, whose side is aimed at point blank by a cannon at *a*. Now, if the vessel were at rest, a ball discharged in this manner would pass through the points *b* and *c*, so that the three points, *a*, *b*, and *c*, would all be in the same straight line. But if the vessel itself move from M toward N, then the ball which entered at *b* would not come out at the opposite point, *c*, but at some other point, *d*, as much nearer to the stern, as is equal to the distance gone over by the vessel, from M to N, during the time of passage of the ball through her. The lines *b c* and *b d*, therefore, form an angle at *b*, whose magnitude depends on the position of *b c* and *b d*. The greater the velocity of the ball, as compared with the ship, the less the angle. Next,

Fig. 194.



What is meant by the aberration of the fixed stars? Give an illustration of it. What is the value of the angle of aberration? What is the velocity of light as thus determined?

for the ship substitute in your mind the earth, and for the cannon any of the fixed stars; let the velocity, *b c*, of the cannon-ball now stand for that of light, and let *d c* be the velocity of the earth in her orbit. The angle *d b c*, is called the angle of aberration. It amounts to 20¼ seconds for all the stars; for they all exhibit the same alteration in their apparent position, being more backward than they really are in the direction of the earth's annual motion, as Bradley discovered. By a simple trigonometrical calculation, it appears from these facts that the velocity of light is 195,000 miles per second, a result nearly coinciding with the former.

LECTURE XXXVII.

REFLEXION OF LIGHT.—*Different kinds of Mirrors.—General Law of Reflexion.—Case of Parallel, Converging, and Diverging Rays on Plane Mirrors.—The Kaleidoscope.—Properties of Spherical Concave Mirrors.—Properties of Spherical Convex Mirrors.—Spherical Aberration.—Mirrors of other Forms.—Cylindrical Mirrors.*

WHEN a ray of light falls upon a surface, it may be reflected, or transmitted, or absorbed.

We therefore proceed to the study of these three incidents, which may happen to light, commencing with reflexion.

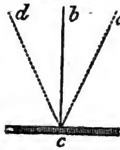
Reflecting surfaces in optics are called mirrors; they are of various kinds, as of polished metal or glass. They differ also as respects the figure of their surfaces, being plane, convex, or concave; and again they are divided into such as are spherical, parabolic, elliptical, &c.

The general law which is at the foundation of this part of optics—the law of reflexion—is as follows:

The angle of reflexion is equal to the angle of Incidence, the reflected ray is in the opposite side of the perpendicular, and the perpendicular, the incident, and the reflected rays are all in the same plane.

When a ray of light falls on a surface what may happen to it? What is meant by reflecting surfaces? What is the general law of reflexion?

Fig. 195.



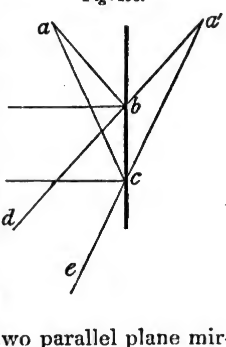
Thus, let *c*, *Fig*. 195, be the reflecting surface; *b c* a perpendicular to it at any point, *a c* a ray incident on the same point; the path of the reflected ray under the foregoing law will be *c d;* such, that it is on the opposite side of the perpendicular to the incident ray, that *a c*, *c b*, and *c d*, are all in the same plane, and that the angle of incidence, *a c b*, is equal to the angle of reflexion, *b c d*.

Reflexion from mirror surfaces may be studied under three divisions: reflexion from plane, from concave, and from convex mirrors.

When parallel rays fall on a plane mirror, they will be reflected parallel, and divergent and convergent rays will respectively diverge and converge at angles equal to their angles of incidence.

When rays diverging from a point fall on a mirror, they are reflected from it in such a manner as though they proceeded from a point as far behind it as it is in reality before it. This principle has already been explained in Lecture XXXII, *Fig*. 176. It is illustrated in *Fig*. 196. Thus, if from the point *a* two rays, *a b*, *a c*, diverge, they will, under the general law, be respectively reflected along *b d*, *c e;* and if these be produced they will intersect at *a*′, as far behind the mirror as *a* is before it. The point *a*′ is called the virtual focus.

Fig. 196.



From this it appears that any object seen in a plane mirror appears to be as far behind it as it is in reality before it.

If an object is placed between two parallel plane mirrors each will produce a reflected image, and will also repeat the one reflected by the other. The consequence is, therefore, that there is an indefinite number of images produced, and in reality the number would be infinite

Illustrate this law by *Fig*. 195. What three kinds of mirrors are there? When parallel, divergent, or convergent rays fall on a plane mirror, what happens to them after reflexion? What does *Fig*. 196 illustrate? What is the effect of two parallel plane mirrors?

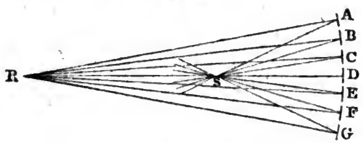
were the light not gradually enfeebled by loss at each successive reflexion.

The kaleidoscope is a tube containing two plane mirrors, which run through it lengthwise, and are generally inclined at an angle of 60°.* At one end of the tube is an arrangement by which pieces of colored glass or other objects may be held, and at the other there is a cap with a small aperture. On placing the eye at this aperture the objects are reflected, and form a beautiful hexagonal combination, their position and appearance may be varied by turning the tube round on its axis.

Concave and convex mirrors are commonly ground to a spherical figure, though other figures, such as ellipsoids, parabaloids, &c., are occasionally used for special purposes. It is the properties of spherical concaves that we shall first describe.

The general action of a spherical mirror may be understood by regarding it as made up of a great number of small plane mirrors, as A, B, C, D, E, F, G, *Fig.* 197. On such a combination of small mirrors, let rays emanating from R impinge. The different degrees of obliquity under which they fall upon the mirrors cause them to follow new paths after reflexion, so that they converge to the point S as to a focus.

Fig. 197.



The problem of determining the path of a ray after it has been reflected is solved by first drawing a perpendicular to the surface at the point of impact, and then drawing a line on the opposite side of this perpendicular, making with it an angle equal to that of the angle of incidence of the incident ray. Thus, let *r*, *s*, *Fig.* 198, be an incident ray falling on any reflecting surface at *s*. To find the path it will take after reflexion, we first draw *s c*, a perpendicular to the surface at the point of impact, s. And then draw the line *s f* on the opposite side of the

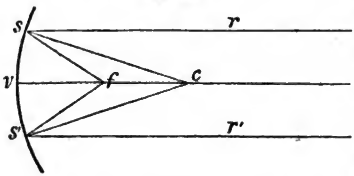
What is the kaleidoscope? What is the ordinary figure of concave and convex mirrors? How may the general action of these mirrors be conceived? Describe the method for determining the path of rays after reflexion.

perpendicular *c s*, such, that the angle *c s f* is equal to the angle *c s r*. This is nothing but an application of the general law of reflexion, that the angles of incidence and reflexion are equal to one another, and are on opposite sides of the perpendicular.

When rays of light diverge from the center of a spherical concave mirror, after reflexion they converge back to the same point. For, from the nature of such a surface, lines drawn from its center are perpendicular to the point to which they are drawn, every ray, therefore, impinges perpendicularly upon the surface and returns to the center again.

When parallel rays of light fall on the surface of a spherical mirror, the aperture or diameter of which is not very large, they are reflected to a point half way between the surface and center of the mirror. Thus, let *r s* *r′ s′* be parallel rays falling on the mirror *s s′*, the aperture, *s s′*, of which is only a few degrees, these rays, after reflexion, will be found converging to the point *f*, which is called the *principal focus*, half way between the vertex of the mirror, *v*, and its center, *c;* for if we draw the radii, *c s c s′*, these lines are perpendiculars to the mirror at the points on which they fall; then make the angles *c s f* equal *c s r*, and *c s′ f* equal *c s′ r′*, and it is easy to prove that the point *f* is midway between *v* and *c*.

Fig. 198.

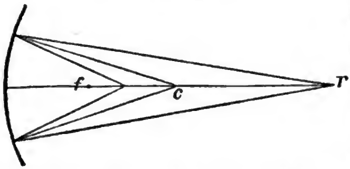


But if the aperture, *s s′*, of the mirror exceeds a few degrees, it may be proved geometrically that the rays no longer converge to the focus, *f*, but, as the aperture increases, are found nearer and nearer to the vertex, *v*, until finally, were it not for the opacity of the mirror, they would fall at the back of it. As this deviation is dependent on the spherical figure of the mirror, it is termed aberration of sphericity.

When rays diverge from the center of a spherical concave mirror, where will they be found after reflexion? What is the case when parallel rays fall on a spherical mirror? Why is the result limited to mirrors of small aperture? What is meant by aberration of sphericity?

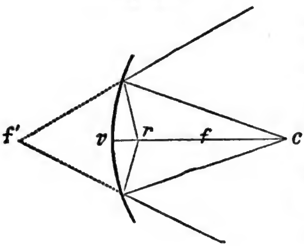
Conversely, if diverging rays issue from a lucid point, *f*, *Fig.* 198, half way between the vertex and center of a spherical mirror of limited aperture, they will be reflected in parallel lines.

Fig. 199.



Rays coming from any point, *r*, *Fig.* 199, at a finite distance beyond the center of the mirror, will be reflected so as to fall between the focus, *f*, and the center, *c*.

Fig. 200.



Rays coming from a point, *r*, *Fig.* 200, between the focus, *f*, and the vertex, *v*, will diverge after reflexion. Under such circumstances a virtual focus, *f′*, exists at the back of the mirror.

Concave mirrors give rise to the formation of images in their foci. This fact may be shown experimentally by placing a candle at a certain distance in front of such a mirror and a small screen of paper at the focus. On this paper will be seen an image of the flame, beautifully clear and distinct, but inverted. The relative size and position of this image varies according to the distance of the object from the vertex of the mirror.

The second variety of curved mirrors is the convex; their chief properties are as follows:

When parallel rays fall on the surface of a convex mirror, they become divergent after reflexion; for let *s s′* be such a mirror, and *r s r′ s′* rays parallel to its axis falling on it, let *c* be the center of the mirror, and draw *c s c s′*, which will be respectively perpendicular to the mirror at the points *s* and *s′*; then for the reflected rays, make the

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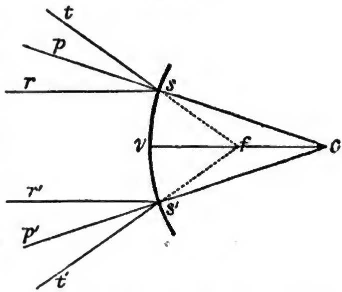
What is the case when diverging rays issue from the focus of a spherical mirror? What when they come from a finite distance beyond the center? What when they come from between the focus and the vertex? How may it be proved that concave mirrors form images? What is the second variety of mirrors? When parallel rays fall on a convex mirror, what path do they take?

angle, $t\ s\ p$, equal to $p\ s\ r$, and the angle, $t'\ s'\ p'$, equal to $p'\ s'\ r'$. It may then be demonstrated, that not only do these reflected rays diverge, but if they be produced through the mirror till they intersect, they will give a virtual focus at f, half way between the vertex of the mirror, v, and its center, c, so long as the mirror is of a limited aperture.

Fig. 201.



In a similar manner it may be proved that diverging rays, falling on a convex mirror, become more divergent.

To avoid the effect of spherical aberration, it has been proposed to give to mirrors other forms than the spherical. Some are ground to a paraboloidal, and others to an ellipsoidal figure. Of the properties of such surfaces I have already spoken, under the theory of undulations, in Lecture XXXII; and the effects remain the same, whether we consider light as consisting of innumerable small particles, shot forth with great velocity, or of undulations arising in an elastic ether. In both cases parallel rays, falling on a paraboloidal mirror, are accurately converged to the focus, whatever the aperture of the mirror may be; and in ellipsoidal ones, rays diverging from one of the foci, are collected together in the other. Occasionally, for the purposes of amusement, mirrors are ground to cylindrical or conical figures; they distort the appearance of objects presented to them, or reflect, in proper proportions, the images of distorted or ludicrous paintings.

Why are paraboloidal and ellipsoidal mirrors sometimes used? What is the effect of the former on parallel rays? What of the latter on rays issuing from one of the foci? What are the effects of cylindrical mirrors?

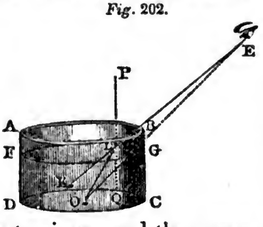
LECTURE XXXVIII.

REFRACTION OF LIGHT.—*Refractive Action described.—Law of the Sines.—Relation of the Refractive Power with other Qualities.—Total Reflexion.—Rays on plane Surfaces.—The Prism.—Action of the Prism on a Ray.—The Multiplying-Glass.*

WHEN a ray of light passes out of one medium into another of a different density, its rectilinear progress is disturbed, and it bends into a new path. This phenomenon is designated the refraction of light.

Thus, if a sunbeam, entering through a small hole in the shutter of a dark room, falls on the surface of some water contained in a vessel, the beam, instead of passing on in a straight line, as it would have done had the water not intervened, is bent or broken at the point of incidence, and moves in the new direction.

Fig. 202.



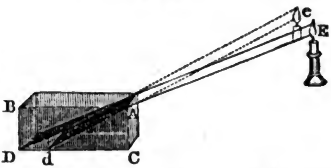
In the same way, also, if a coin or any other object, O, *Fig.* 202, be placed at the bottom of an empty bowl, A B C D, and the eye at E so situated that it cannot perceive the coin, the edge of the vessel intervening, if we pour in water the object comes into view; and the cause of this is the same as in the former illustration: for while the vessel is empty the ray is obstructed by the edge of the bowl, as at O G E, but when water is poured in to the height F G, refraction at the point L, from the perpendicular, P Q, ensues; and now the ray takes the course O L E, and entering the eye at E, the object appears at K, in the line E L K.

For the same reason oars or straight sticks immersed in water look broken, and the bottom of a stream seems at a much less depth than what it actually is.

What is meant by the refraction of light? Explain the illustrations of this phenomenon as given in *Figs.* 202 and 203.

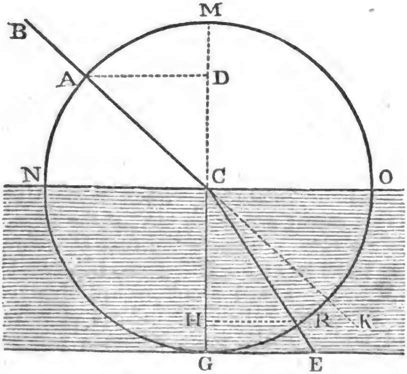
The same result ensues under the circumstances represented in *Fig.* 203, in which E represents a candle, the rays of which fall on a rectangular box, A B C D, under such circumstances as to cast the shadow of the side A C, so as to fall at D. If the box be now filled with water, every thing remaining as before, the shadow will leave the point D and go to d, the rays undergoing refraction as they enter the liquid; and if the eye could be placed at d, it would see the candle at e, in the direction of d A produced.

Fig. 203.



Let N O, *Fig.* 204, be a refracting surface, and C the

Fig. 204.



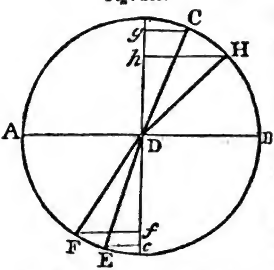
point of incidence of a ray, B C, C E the course of the refracted ray, and C K the course the ray would have taken had not refraction ensued. With the point of incidence, C, as a center, describe a circle, N M O G, and from A and R draw the lines A D, R H at right angles to the perpendicular M G to the point C. Then A C M will be the angle of incidence, R C G the angle of refraction; A D is the sine of the angle of incidence, and H R the sine of the angle of refraction. Now in every medium

Explain *Fig.* 204. What is the angle of incidence? What is the angle of refraction? Which are the sines of those angles?

these lines have a fixed relation to one another, and the general law of refraction is as follows:—

In each medium the sine of the angle of incidence is in a constant ratio to the sine of the angle of refraction; the incident, the perpendicular, and the refracted ray are all in the same place, which is always at right angles to the plane of the refracting medium.

Fig. 205.



To a beginner, this law of the constancy of sines may be explained as follows:—Let C D, *Fig.* 205, be a ray falling on a medium, A B, in the point D, where it undergoes refraction and takes the direction D E. Its sine of incidence, as just explained, is C *g*, and its sine of refraction E *e;* and let us suppose that the medium is of such a nature that the sine of refraction is one half the sine of incidence—that is, E *e* is half C *g*. Moreover, let there be a second ray, H D, incident also at the point D, and refracted along D F; H *h* will be its sine of incidence, and F *f* its sine of refraction; and by the law F *f* will be exactly one half H *h*. The proportion or relation between these sines differs when different media are used, but for the same medium it is always the same. Thus, in the case of water, the proportion is as 1.366 to 1; for flint-glass, 1.584 to 1; for diamond, 2.487 to 1. These numbers are obtained by experiment. They are called the indices of refraction of bodies, and tables of the more common substances are given in the larger works on optics.

No general law has as yet been discovered which would enable us to predict the refractive power of bodies from any of their other qualities; but it has been noticed that inflammable bodies are commonly more powerful than incombustible ones, and those that are dense are more energetic than those that are rare.

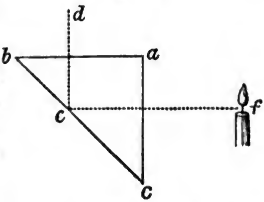
When a ray of light passes out of a rare into a dense

What relation do these sines bear to one another? Explain the law of the constancy of the sines as given in *Fig.* 205. What is the rate for water, flint-glass, and diamond? What is meant by indices of refraction? Is the refractive power of bodies connected with any other property?

medium, it is refracted *toward* the perpendicular. *Fig.* 203 is an illustration—the rays passing from air into water. But when a ray passes from a dense into a rarer medium it is refracted *from* the perpendicular. *Fig.* 202 is an example—the rays passing from water into air.

In every case when a ray falls on the surface of any medium whatever, it is only a portion which is transmitted, a portion being always reflected. If in a dark room we receive a sunbeam on the surface of some water, this division into a reflected and a refracted ray is very evident: and when a ray is about to pass out of a highly refractive medium into one that is less so, making the angle of incidence so large that the angle of refraction is equal to or exceeds 90°, total reflexion ensues. This may be readily shown by allowing the rays from a candle, *f*, or any other object, to fall on the second face, *b c*, of a glass prism, *a b c*, *Fig.* 206; the eye placed at *d* will receive the reflected ray, *d e*, and it will be perceived that the face *b c* of the glass, when exposed to the daylight, appears as though it were silvered, reflecting perfectly all objects exposed to its front, *a c*.

Fig. 206.



As with the reflexion of light, so with refraction—it is to be considered as taking place on plane, convex, and concave surfaces.

When parallel rays fall upon a plane refracting surface they continue parallel after refraction. This must necessarily be the case on account of the uniform action of the medium.

If divergent rays fall upon a plane of greater refractive power than the medium through which they have come, they will be less divergent than before. Thus, from the point *a* let the rays *a b*, *a b′* diverge; after suffering refraction they will pass in the paths *b c*, *b′ c′*, and if these

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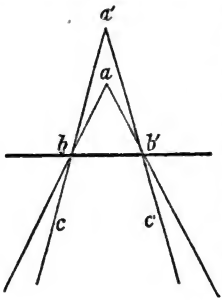
When is light refracted toward and when from the perpendicular? Is the whole of the light transmitted? Under what circumstance does total reflexion take place? What ensues when parallel rays fall on a plane surface? What is the case with diverging ones?

Fig. 207.



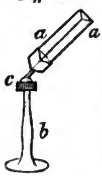
lines be projected, they will intersect at a', but $a'\ b$, $a'\ b'$ are less divergent than $a\ b$, $a\ b'$.

If, on the contrary, rays pass from a medium of greater to one of less refractive power, they will be more divergent after refraction. For this reason bodies under water appear nearer the surface than they actually are.

When parallel rays of light pass through a medium bounded by planes that are parallel, as through a plate of glass, they will continue still parallel to one another, and to their original direction, after refraction. For this reason, therefore, we see through such plates of glass objects in their natural positions and relation.

The optical prism is a transparent medium, having

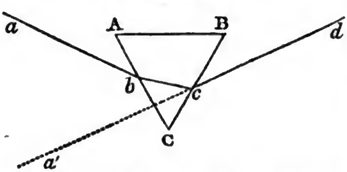
Fig. 208.



plane surfaces inclined to one another. It is usually a wedge-shaped piece of glass, *a a*, *Fig.* 208, which can be turned into any suitable position, on a ball and socket-joint, *c*, and is supported on a stand, *b*. As this instrument is of great use in optical researches, we shall describe the path of a ray of light through it more minutely.

Let, therefore, A B C, *Fig.* 209, be such a glass prism

Fig. 209.



seen endwise, and let *a b* be a ray of light incident at *b*. As this ray is passing from a rarer to a denser medium it is refracted toward the perpendicular to an extent dependent on the refractive power of the glass of which the prism is composed, and therefore pursues a new path, *b c*, through the glass; at *c* it again undergoes refraction, and now passing from a denser to a rarer medium, takes

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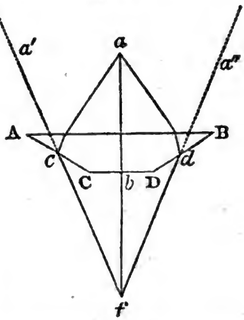
What is the case when parallel rays pass through media with plane and parallel surfaces? What is a prism? Describe the path of a ray of light through this instrument.

a new course, $c\ d$. To an eye placed at d, and looking through the prism, an object, a, seems as though it were at a', in the straight line $d\ c$ continued. Through this instrument, therefore, the position of objects is changed, the refracted ray, $c\ d$, proceeding toward the back, A B, of the prism.

But the prism in actual practice gives rise to far more complicated and interesting effects, to be described hereafter, when we come to speak of the colors of light.

Fig. 210.



The multiplying-glass is a transparent body, having several inclined faces. Its construction and action are represented at *Fig.* 210. Let A B be a plane face, C D also plane and parallel to it, but A C and D B inclined. Now let rays come from any object, a, those, $a\ b$, which fall perpendicularly on the two faces will pass without suffering refraction; but those, $a\ c$, $a\ d$, which fall on the inclined faces will be refracted into new paths, $c\ f$, $d\ f$, these portions acting like the prism heretofore described. Consequently, an eye placed at f will see three images of the object in the direction of the lines along which the rays have come—that is, at a', a, a''. Hence the term *multiplying-glass*, because it gives as many images of an object as it has inclined surfaces.

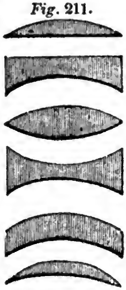
To what other phenomenon does the prism give rise? What is the multiplying-glass? Why does it give as many images of an object as it has faces?

LECTURE XXXIX.

The Action of Lenses.—*Different Forms of Lenses.—General Properties of Convex Lenses.—General Properties of Concave Lenses.—Analogy between Mirrors and Lenses.—Production of Images by Lenses.—Size and Distance of Images.—Visual Angle.—Magnifying Effects.—Burning-Lenses.*

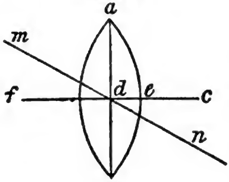
Transparent media having curved surfaces are called lenses. They are of six different kinds, as represented in *Fig*. 211. The plano-convex lens, A, has one surface plane and the other convex, the plano-concave, B, has one surface plane and the other concave; C is the double convex, D the double concave, E the meniscus, and F the concavo-convex.

Fig. 211.



For optical uses lenses are commonly made of glass, but for certain purposes other substances are employed. For example, rock crystal is often used for making spectacle lenses; it is a hard substance, and is not, therefore, so liable to be scratched or injured as glass.

Fig. 212.

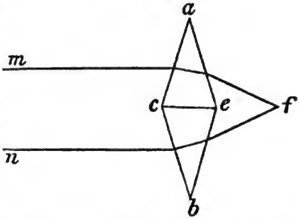


In a lens the point c is called the *geometrical center*, for all lenses are ground to spherical surfaces, and c is the center of their curvature; the aperture of the lens is $a\ b$, and d is its *optical center*; $f\ e$ is the axis, and any ray, $m\ n$, which passes through the optical center, is called a principal ray.

What are lenses? How many kinds of lenses are there? What are they commonly made of? What other substances are sometimes used? What is the geometrical center? What is the optical center? What is a principal ray? What is the aperture?

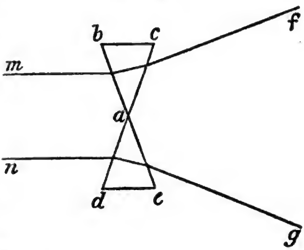
The general action of lenses of all kinds may be understood after what has been said in relation to the prism, of which it was remarked that the refracted ray is bent toward the back. Thus, if we have two prisms, *a c e*, *b c e*, placed back to back, and allow parallel rays of light, *m n*, to fall upon them, these rays, after refraction, being bent from their parallel path toward the back of each prism, will intersect each other in some point, as *f*. Now, there is obviously a strong analogy between the figure of the double convex lens and that of these two prisms; indeed, the former might be regarded as a series of prisms with curved surfaces, and from such consideration it is clear, that when parallel rays fall on a convex lens, they will converge to a focal point.

Fig. 213.



Again, let us suppose that a pair of prisms be placed edge to edge, as shown in *Fig.* 214, and that parallel rays, *m n*, are incident upon them. These rays undergo refraction, as before, toward the back of their respective prisms, *b c*, *d e*, and therefore emerge divergent, as at *f* and *g*. Now, there is an analogy between such a combination of prisms and a concave lens, and we therefore see that the general action of such a lens upon parallel rays is to make them divergent.

Fig. 214.



By the aid of the law of refraction it may be proved that lenses possess the following properties.

Every principal ray which falls upon a convex lens of limited thickness is transmitted without change of direction.

How may the general action of a double convex lens be deduced from that of a pair of prisms? Trace the same action in the case of a double concave lens.

Rays parallel to the axis of a double equi-convex glass lens are brought to a focus at a distance from the optical center equal to the radius of curvature of the lens. But if it be a plano-convex glass the focal distance is twice as great. The focus for parallel rays is called the principal focus.

Rays diverging from the principal focus of a convex lens after refraction become parallel.

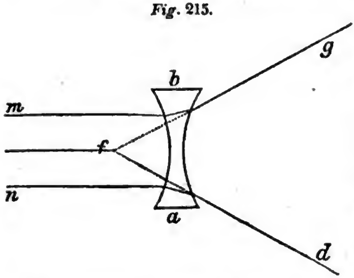
Rays diverging from a point in the axis more distant than the principal focus converge after refraction, their point of convergence being nearer the lens as the point from which they radiated was more distant.

Rays coming from a point in the axis nearer than the principal focus diverge after refraction.

With respect to concave lenses, the chief properties may be described as follows:—

Every principal ray passes without change of direction.

Fig. 215.



Rays parallel to the axis are made divergent. Thus, *m n*, *Figure* 215, being parallel rays falling on the double concave, *a b*, diverge after refraction in the directions *g d*; and if they be produced give rise to a virtual or imaginary focus at *f*.

By concave lenses diverging rays are made still more divergent.

When the effects of lenses are compared with those of mirrors, it will be found that there is an analogy in the action of concave mirrors and convex lenses, and of convex mirrors and concave lenses.

It has already been remarked that concave mirrors give images of external objects in their focus. The same holds good for convex lenses. Thus, if we take a convex lens, and place behind it, at the proper distance, a paper screen, we shall find upon that screen beautiful images of

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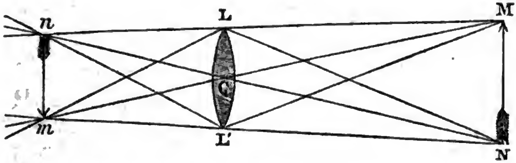
What are the chief properties of convex lenses? What are the chief properties of concave lenses? What is the relation between mirrors and lenses in their effects?

all the objects in front of the lens in an inverted position. The manner in which they form may be understood from *Fig.* 216. Where L′ L is a double convex lens, M N

Fig. 216.



any object, as an arrow, in front of it, the lens will give an inverted image, *n m*, of the object at a proper distance behind. From the point M all the rays, as M L, M C, M L′, after refraction, will converge to a focus, *m*; and from the point N all rays, as N L, N C, N L′, will likewise converge to a focus, *n*; and so, for every intermediate point between M and N, intermediate foci will form between *m* and *n*, and therefore conjointly give rise to an inverted image.

The images thus given by lenses or mirrors may be made visible by being received on white screens or on smoke rising from a combustible body, or directly by the eye placed in a proper position to receive the rays. They then appear as if suspended in the air, and are spoken of as aerial images.

The distance of such images from a lens, and also their magnitude, vary with circumstances.

If the object be very remote, it gives a minute image in the focus of the lens; as it is brought nearer, the image recedes farther, and becomes larger; when it is at a distance equal to twice the focal distance, the image is equidistant from the lens on the opposite side, and is of the same size as the object. As the object approaches still nearer, the image recedes, and now becomes larger than the object. When it reaches the focus, the image is at an infinite distance, the refracted rays being parallel to one another. And, lastly, when the object comes between the focus and the surface of the lens, an erect and

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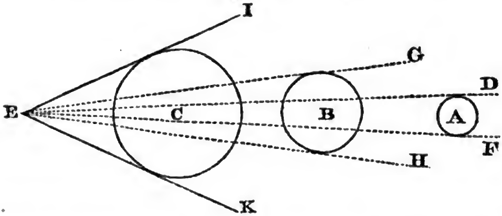
Do convex lenses give rise to the formation of images? How does this effect arise? How may such images be made visible? Under what circumstances do the size and distance of the image vary?

magnified image of the object will appear on the same side of the lens as the object itself. Hence, convex lenses are called magnifying-glasses.

From these considerations, it therefore appears that the

Fig. 217.



magnifying power of lenses is not, as is often popularly supposed, due to the peculiar nature of the glass of which they are made, but to the figure of their surfaces. The dimensions of all objects depend on the angles under which they are seen. A coin at a distance of 100 yards appears of very small size, but as it is brought nearer the eye its size increases; and when only a few inches off, it can obstruct the view of large objects. Thus, if A represent its size at a remote distance, the angle D E F, or the visual angle, is the angle under which it is seen; when brought nearer, at B, the angle is G E H; and at C, increases to I E K. In all cases the apparent size of an object increases as the visual angle increases, and all objects become smaller as their distances increase; and any optical contrivances, either of lenses or mirrors, which can alter the angle at which rays enter the eye and make it larger than it would otherwise be, magnify the objects seen through them.

On these principles concave mirrors and convex lenses magnify, and convex mirrors and concave lenses minify.

From their property of converging parallel rays to a focus, convex lenses and concave mirrors have an interesting application, being used for the production of high temperatures, by converging the rays of the sun. *Fig.* 218 represents such a burning-glass. The parallel rays of the sun

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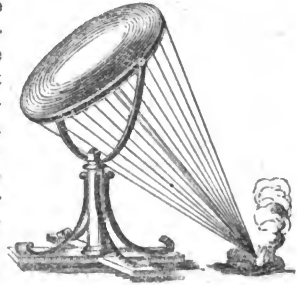
Why are convex lenses magnifying-glasses? On what does this magnifying action depend? What is the visual angle of an object?

Fig. 218.



falling on it are made to converge, and this convergence might be increased by a second smaller lens. At the focal point any small object being exposed its temperature is instantly raised. In such a focus there are few substances that can withstand the heat—brick, slate, and other such earthy matters instantly boil, metals melt, and even volatilize away. During the last century some French chemists, using one of these instruments, found that when a piece of silver is held over gold, fused at the focus, it became gilded over by the vapor that rose from the melted mass. And in the same way gold could be whitened by the vapors of melted silver. The heat attained in this way far exceeds that of the best constructed furnace.

LECTURE XL.

Of Colored Light.—*Action of the Prism.—Refraction and Dispersion.—The Solar Spectrum.—Its Constituent Rays.—They pre-exist in White Light.—Theory of the Different Refrangibility of the Rays of Light.—Different Dispersive Powers.—Irrationality of Dispersion.—Illuminating Effects.—The Fixed Lines.—Calorific Effects.—Chemical Effects.*

In speaking of the action of a prism, in Lect. XXXVIII., it was observed, that it gives rise to many interesting results connected with colored lights. These, which constitute one of the most splendid discoveries of Newton, I next proceed to explain.

Through an aperture, *a*, *Fig.* 219, in the shutter of a dark room let a beam of light, *a e*, enter, and let it be intercepted at some part of its course by a glass prism, seen

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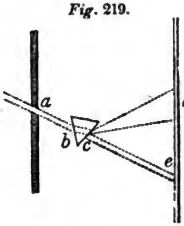
What is a burning glass? Why does it give rise to the production of an intense heat? Mention some of the effects which have been obtained by these instruments. Describe the action of a prism on a ray of light.

endwise at *b c*.. The light will undergo refraction, and in consequence of what has been already stated, will pass in a direction, *d*, toward the back of the prism.

Fig. 219.



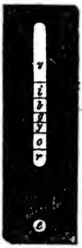
Now, for any thing that has yet been said, it might appear that this refracted ray, on reaching the screen *d e*, would form upon it a white spot similar to that which it would have given at *e*, had not the prism intervened. But when the experiment is made, instead of the light going as a single pencil of uniform width, it spreads out into a fan shape, as is indicated by the dotted lines, and forms on the screen an oblong image of the most splendid colors.

In this beautiful result, two facts, which are wholly distinct, must be remarked: 1st, the light is *refracted* or bent out of its rectilinear path; 2d, it is *dispersed* into an oblong colored figure.

On examining this figure or image, which passes under the name of the solar spectrum, we find it divided into seven well-marked regions. Its lowest portion, that is to say, the part nearest to that to which the light would have gone had not the prism intervened, is of a red color, the most distant is of a violet, and between these other colors may be seen occurring in the following order:—

Red,	Blue,
Orange,	Indigo,
Yellow,	Violet.
Green,	

Fig. 220.



In *Fig*. 220, the order in which they occur is indicated by their initial letters, *e* being the point to which the light would have gone had not the prism intervened.

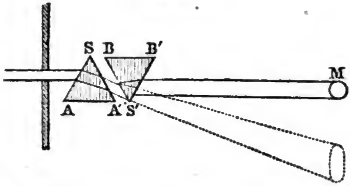
Now, from what source do these splendid colors come? Newton proved that they pre-existed in the white light, which, in reality, is made up of them all taken in proper proportions.

There are many ways in which this important truth can be established. Thus, if we take a second

Is the refracted light white? What two general facts are to be observed? What color is the lowest portion of the spectrum? What is the color of the highest. What is the order of the colors?

prism, B B′ S′, *Fig.* 221, and put it in an inverted position, as respects the first, A A′ S, so that it shall refract again in the opposite direction the rays refracted by the first, they will, after this second refraction, reunite and form a uniform beam, M, of white light, in all respects like the original beam itself.

Fig. 221.



If the production of color were due to any irregular action of the faces of the first prism, the introduction of two more faces in the second prism would only tend to increase the coloration. But so far from this, no sooner is this second prism introduced than the rays reunite and recompose white light. It follows as an inevitable consequence that *white light contains all the seven rays.*

But Newton was not satisfied with this. He further collected the prismatic colored rays together into one focus by means of a lens, and found that they produced a spot of dazzling whiteness. And when he took seven powders, of colors corresponding to the prismatic rays, and ground them intimately together in a mortar, he found that the resulting powder had a whitish aspect; or if, on the surface of a wheel which could be made to spin round very fast on its axis, colored spaces were painted, when the wheel was made to turn so that the eye could no longer distinguish the separate tints, the whole assumed a whitish-gray appearance.

By many experiments Newton proved that the true cause of this development of brilliant colors from a ray of white light by the prism, is due to the fact that that instrument does not refract all the colors alike. Thus, it could be completely shown, in the case of any transparent medium, that the violet-ray was far more refrangible than the red, or more disturbed by such a medium from its course. In this originated the doctrine of "the different refrangibility of the rays of light."

How may it be proved by two prisms that all these colors pre-exist in white light? What may be proved by reuniting the rays by a lens? What by colored powders or a painted wheel? What is the cause of this development of colors?

On examining the order of colors in the spectrum, we find, in reality, as in *Fig.* 220, that the red is least disturbed from its course, and the other colors follow in a fixed order. The red, therefore, is spoken of as the least refrangible ray, the violet as the most, and the other colors as intermediately refrangible.

We now see the cause of the development of these colors from white light, which contains them all. If the prism acted on every ray alike, it would merely produce a white spot at *d*, analogous to that at *e*, *Fig.* 220, but as it acts unequally it separates the colored rays from one another, and gives rise to the spectrum.

On examining prisms of different transparent media, we find that they act very differently—some dispersing the rays far more powerfully than others and giving rise, under the same circumstances, to spectra of very different lengths. In the treatises on optics, tables of the dispersive powers of different transparent bodies are given: thus it appears that oil of cassia is more dispersive than rock-salt, rock-salt more than water, and water more than fluor spar.

Moreover, in many instances it has been found that if we use different prisms which give spectra of equal lengths, the colored spaces are unequally spread out. This shows that media differ in their refracting action upon particular rays, some acting upon one color more powerfully than another. This is called irrationality of dispersion.

The different colored rays of light are not equally luminous—that is to say, do not impress our eyes with an equal brilliancy. If a piece of finely-printed paper be placed in the spectrum, we can read the letters at a much greater distance in the yellow than in the other regions, and from this the light declines on either hand, and gradually fades away in the violet and the red.

It has also been found that the colors are not continuous throughout, but that when delicate means of examination are resorted to the spectrum is seen to be crossed with many hundreds of dark lines, irregularly scattered through it. A representation of some of the larger of these is

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To what doctrine did this discovery give rise? Do different media disperse to the same or different extents? What is meant by irrationality of dispersion? Are all the rays equally luminous to the eye? How may this be proved?

given in *Fig.* 222. It is curious that though they exist in the sun-light, and in that of the planets, they are not found in the spectra of ordinary artificial lights; and, indeed, the electric spark gives a light which is crossed by brilliant lines instead of black ones. The chief fixed lines are designated by the letters of the alphabet, as shown in the figure.

Fig. 222.

The light of the sun is accompanied by heat. Dr. Herschel found that the different colored prismatic spaces possess very different power over the thermometer. The heat is least in the violet, and continually increases as we descend through the colors, the red being the hottest of them all. But below this, and out of the spectrum, when there is no light at all, the maximum of heat is found. The heat of the sunbeam is, therefore, refrangible, but is less refrangible than the red ray of light.

Late discoveries have shown that every ray of light can produce specific changes in compound bodies. Thus it is the yellow ray which controls the growth of plants, and makes their leaves turn green; the blue ray which brings about a peculiar decomposition of the iodides and chlorides of silver, bodies which are used in photogenic drawing. Those substances which phosphoresce after exposure to the sun are differently affected by the different rays—the more refrangible producing their glow, and the less extinguishing them.

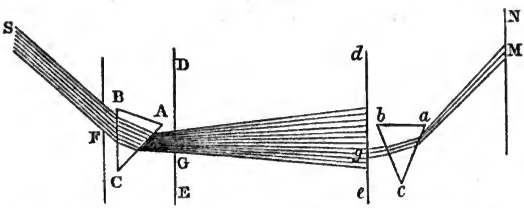
Describe the fixed lines of the spectrum. How are they distinguished? What are the calorific effects of the spectrum? Which is the hottest space? What are the chemical effects?

LECTURE XLI.

OF COLORED LIGHT.—*Properties of Homogeneous Light.—Formation of Compound Colors.—Chromatic Aberration of Lenses.—Achromatic Prism.—Achromatic Lens.—Imperfect Achromaticity from Irrationality of Dispersion.—Cause of the Colors of Opaque Objects.—Effects of Monochromatic Lights.—Colors of Transparent Media.*

EACH color of the prismatic spectrum consists of homogeneous light. It can no longer be dispersed into other colors, or changed by refraction in any manner. Thus,

Fig. 223.



let a ray of light, S, *Fig.* 223, enter through an aperture, F, into a dark room, and be dispersed by the prism, A B C; through a hole, G, in a screen, D E, let the resulting spectrum pass, and be received on a second screen, *d e*, placed some distance behind; in this let there be a small opening, *g*, through which one of the colored rays of the spectrum, formed by A B C, may pass and be received on a second prism, *a b c*. It will undergo refraction, and pass to the position M on the screen, N M. But it will not be dispersed, nor will new colors arise from it; and it is immaterial which particular ray is made to pass the opening at *g*, the same result is uniformly obtained.

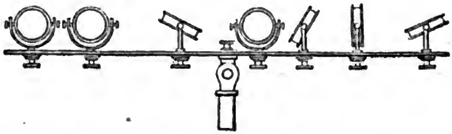
Homogeneous or monochromatic colors, therefore, cannot suffer dispersion.

By the aid of the instrument *Fig.* 224, which consists

How may it be proved that homogeneous light undergoes no further dispersion? What is the use of the instrument represented in *Fig.* 224?

of a series of little plane mirrors set upon a frame, we

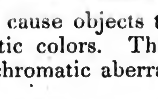
Fig. 224.



can demonstrate, in a very striking manner, the constitution of different kinds of lights; for if this instrument be placed in such a manner as to receive the prismatic spectrum, by turning its mirrors in a suitable position we can throw the rays they receive at pleasure on a screen. Thus, if we mix together the red and blue ray, a purple results; if the red and yellow, an orange; and if the yellow and blue, a green. It is obvious, therefore, that of the colors we have enumerated in Lecture XL, as the seven prismatic rays, the green, the indigo, and violet may be compound, or secondary ones, arising from the intermixture of red, yellow, and blue, which by many philosophers are looked upon as the three primitive colors.

We have already remarked that there is an analogy between prisms and lenses in their action on the rays of light, and have shown how rays become converging or diverging in their passage through those transparent solids. In the same manner it also follows, that as prisms produce dispersion as well as refraction, so, too, must lenses: for, by considering the action of pairs of prisms, as in *Fig.* 225, or as we have already done in Lecture XXXIX., we arrive at the action of concave and convex lenses, and find that as refrangibility differs for different rays—being least for the red and most for the violet—a lens acting unequally will cause objects to be seen through it fringed with prismatic colors. This phenomenon passes under the title of chromatic aberration of lenses.

Fig. 225.

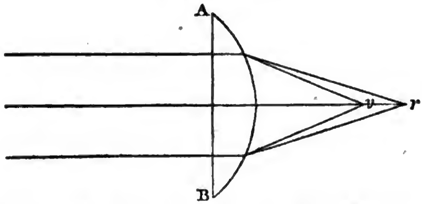


To understand more clearly the nature of this, let parallel rays of red light fall upon a plano-convex lens, A

Which of the colors of the spectrum may be regarded as compound, and which as simple? How may it be shown that lenses produce colors as well as prisms?

B, *Fig*. 226, and be converged by it to a focus in the point *r*, the distance of which from the lens is measured. Then

Fig. 226.



let parallel rays of violet light, in like manner, fall on the lens, and be converged by it to a focus, *v*. On being measured, it will be found that this focus is much nearer the lens than the other; and the cause of it is plainly due to the unequal refrangibility of the two kinds of light. The violet is the more refrangible, and is, therefore, more powerfully acted on by the lens, and made to converge more rapidly.

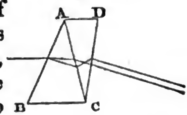
But this which we have been tracing in the case of homogeneous rays must of course take place in the compound white light. On the same principle that the prism separates the white light into its constituent rays by acting unequally on them, so, too, will the lens. Parallel rays of white light falling on a lens, such as Fig. 226, are not, therefore, converged to one common focus, as represented in Lecture XXXIX, but in reality give rise to a series of foci of different colors, the red being the most remote from the lens, and the violet nearest.

In some of the most important optical instruments it is absolutely necessary that this defect should be avoided, and that a method should be hit upon by which light may be refracted without being dispersed. Newton, who believed that it was impossible to succeed with this, gave up the improvement of the refracting telescope, in which it is required that images should be formed without chromatic dispersion, as hopeless. But, subsequently, it was shown that refraction without dispersion can be effected. This is done by employing two bodies having equal refractive, but unequal dispersive powers. Those which

What is the effect of a plano-convex lens on parallel rays of red and blue light, respectively? What is the effect on white light?

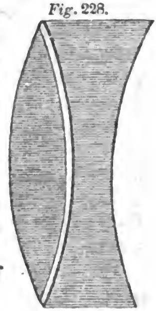
are commonly selected are crown and flint glass, which refract nearly equally. The index for crown being about 1·53, and that of flint 1·60; but the dispersion of good flint glass is twice that of crown.

Fig. 227.



If, now, we take two prisms, A B C, *Fig.* 227, being of crown, and A C D, of flint glass, and place them, with their bases in opposite ways, the refracting angle, C, of the latter being half that of A, the former, or, in other words, adjusted to their relative dispersive powers, it will be found that a ray of light passes through the compound prism, undergoing refraction, and emerging without dispersion; for the incident ray, in its passage through the crown prism will be dispersed into the colored rays, and these, falling on the flint prism—the dispersive power of which we assume to be double, and acting in the opposite direction—will be refracted in the opposite direction, and emerge undispersed. Such an instrument is called an achromatic prism.

Fig. 228.



The same principle can, of course, be used in the construction of lenses, between which and prisms there is that general analogy heretofore spoken of. The achromatic lens consists of a concave lens of flint and a convex one of crown, the curvatures of each being adjusted on the same principle as the angles of the achromatic prism are determined. Such an arrangement is represented in *Fig.* 228. It gives in its focus the images of objects in their natural colors, and nearly devoid of fringes.

But in practice, it has been found impossible, by any such arrangement, to effect the total destruction of color. The edges of luminous bodies seen through such lenses are fringed with color to a slight extent. This arises from the circumstance that the dispersive powers of the media employed are not the same for every colored ray. The simple achromatic lens, *Fig.* 228, will collect the ex-

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How may refraction without dispersion be performed? Describe the structure of the achromatic prism? What is its mode of action? Describe the construction of the achromatic lens. Why are there with these lenses residual fringes?

treme rays together; but leaves the intermediate ones, to a small extent, outstanding.

The theory of the compound constitution of light enables us to account, in a clear manner, for the colors of natural objects. Those which exhibit themselves to us as white merely reflect back to the eye the white light which falls on them, and the black ones absorb all the incident rays. The general reason of coloration is, therefore, the absorption of one or other tint, and the reflection of the rest of the spectral colors. Thus, an object looks blue because it reflects the blue rays more copiously than any others, absorbing the greater part of the rest. And the same explanation applies to red or yellow, and, indeed, to any compound colors, such as orange, green, &c. That colored bodies do, in this way, reflect one class of rays more copiously than others may be proved by placing them in the spectrum. Thus, a red wafer seems of a dusky tint in the blue or violet regions, but of a brilliant red in the red rays.

On the same principles we account for the singular results which arise when monochromatic lights fall on surfaces of any kind. Thus, when spirits of wine is mixed with salt in a plate, and set on fire, the flame is a monochromatic yellow—that is, a yellow unaccompanied by any other ray. If the variously colored objects in a room are illuminated with such a light they assume an extraordinary appearance: the human countenance, for example, taking on a ghastly and death-like aspect; the red of the lips and the cheeks is no longer red, for no red light falls on it; it therefore assumes a grayish tint.

The colors of transparent bodies, such as stained glass and colored solutions, arise from the absorption of one class of rays and the transmission of the rest. Thus, there are red glasses and red solutions which permit the red ray alone to traverse them, and totally extinguish every other. But, in most cases, the colors of transparent, and also of opaque bodies, are far from being monochromatic. They consist, in reality, of a great number

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How may the colors of natural objects be accounted for? What is the cause of whiteness and blackness? How can it be proved that bodies reflect some rays in preference to others? What is monochromatic light? What is the cause of the singular appearance of objects seen by such lights? What is the cause of the colors of transparent bodies?

of different rays. Thus, common blue-stained glass transmits almost all the blue light that falls upon it, and, in addition, a little yellow and red.

LECTURE XLII.

UNDULATORY THEORY OF LIGHT.—*Two Theories of Light.—Applications of the Corpuscular Theory.—Undulatory Theory.—Length of Waves is the cause of Color.—Determination of Periods of Vibration.—Interference of Light.—Explanations of Newton's Rings, and Colors of thin Plates.—Diffraction of Light.*

IT has been stated that there are two different theories respecting the nature of light—the corpuscular and the undulatory. In accounting for the facts in relation to the production of colors, it is assumed that, in the former, there are various particles of luminous matter answering to the various colors of the rays, and which, either alone or by their admixture, give rise to the different tints we see. In white light they all exist, and are separated from one another by the prism, because of an attractive force which such a transparent body exerts; and that attractive force being unequal for the different color-giving particles, difference of refrangibility results. The colors of natural objects on this theory are explained by supposing that some of the color-giving particles are reflected or transmitted, and others stifled or stopped by the body on which they fall. The phenomena of reflection by polished surfaces are therefore reduced to the impact of elastic bodies; and in the same way that a ball is repelled from a wall against which it is thrown, so these little particles are repelled, making their angle of reflexion equal to their angle of incidence. But while there are many of the phenomena of light, such as reflexion, refraction, dispersion, and coloration, which can be accounted for on these principles, there are others which

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What are the two theories of light? What is the nature of the corpuscular theory? On its principles what is the constitution of white light? How does it account for difference of refrangibility and the colors of natural objects? How does it account for the phenomena of reflexion?

the emanation or corpuscular theory cannot meet. These are, however, explained in a simple and beautiful manner by the other theory.

The undulatory theory rests upon the fact that there exists throughout the universe an elastic medium called THE ETHER, in which vibratory movements can be established very much after the manner that sounds arise in the air. Whatever, therefore, has been said in Lectures XXXI, &c., respecting the mechanism and general principles of undulatory movements applies here. Waves in the ether are reflected, and made to converge or diverge on the same principles that analogous results take place for waves upon water or sounds in the air. It will have been observed already that the reflexions of undulations from plane, spherical, elliptic, or parabolic surfaces, as given in Lecture XXXII, are identically the same as those which we have described for light in Lecture XXXVII.

From the phenomena of sound we can draw analogies which illustrate in a beautiful manner the phenomena of light: for, as the different notes of the gamut arise from undulations of greater or less frequency, so do the colors of light arise from similar modifications in the vibrations of the ether. Those vibrations that are most rapid impress our eyes with the sensation of violet, and those that are slower with the sensation of red. The different colors of light are, therefore, analogous to the different notes of sound.

In Lecture XXXIII it was shown how the frequency of vibration which could give rise to any musical note might be determined, and it appeared that the ear could detect vibrations, as sound through a range commencing with 15 and reaching as far as 48,000 in a second. The frequency of vibration in the ether required for the production of any color has also been determined, and the lengths of the waves corresponding. The following table gives these results. The inch being supposed to be divided into ten millions of equal parts, of those parts the wave lengths are:—

On what does the undulatory theory rest? Do the general laws of undulations apply to the phenomena of light? What analogy is there between sound and light? How do the colors of light compare with the notes of sound?

For Red light	. . . .	256
Orange "	. . . .	240
Yellow "	. . . .	227
Green "	. . . .	211
Blue "	. . . .	196
Indigo "	. . . .	185
Violet "	. . . .	174

More recent investigations have proved the remarkable fact that the length of the most refrangible violet wave being taken as one, that of the least refrangible red will be equal to two, and the most brilliant part of the yellow one and a half.

Knowing the length of a wave in the ether required for the production of any particular color of light, and the rate of propagation through the ether, which is 195,000 miles in a second, we obtain the number of vibrations executed in one second, by dividing the latter by the former.

From this it appears that if a single second of time be divided into one million of equal parts, a wave of red light vibrates 458 millions of times in that short interval, and a wave of violet light 727 millions of times.

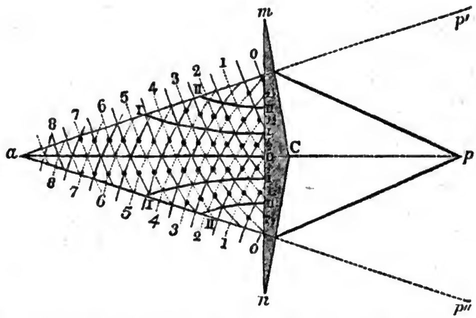
Further, whatever has been said in Lectures XXXI XXXII, in reference to the interference of waves, must necessarily, on this theory, apply to light. Indeed, it was the beautiful manner in which some of the most incomprehensible facts in optics were thus explained, that has led to its almost universal adoption in modern times. That light added to light should produce darkness, seems to be entirely beyond explanation on the corpuscular theory; but it is as direct a consequence of the undulatory, as that sound added to sound may produce silence.

From a lucid point, *p*, *Fig.* 229, let rays of light fall upon a double prism, *m n*, the angle of which, at C, is very obtuse. From what has been said respecting the multiplying-glass (Lecture XXXVIII), it appears that an eye applied at *a* would see the point *p* double, as at p' and p''. Between these images there is also perceived a number of bright and dark lines perpendicular to a line joining p' and p''. On covering one half the prism the lines disappear, and only one image is seen.

What relation of wave length exists between the least, the intermediate, and the most refrangible rays? How may the frequency of vibrations be determined from the wave length? What is that frequency in the case of red and violet light? Does interference of luminous waves take place? How is this exhibited by the double prism, *Fig.* 229?

This alternation of light and darkness is caused by ethereal waves from the points p' and p'' crossing one another, and giving rise to interference. If, therefore, with

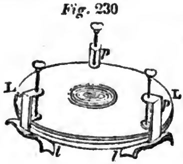
Fig. 229.



those points as centers, we draw circular arcs, 0, 1, 2, 3, 4, &c., these may represent waves, the alternate lines between them being half waves. It will be perceived that wherever two whole waves or two half waves encounter, they mutually increase each other's effect; but if the intersection takes place at points where the vibrations are in opposite directions, interference, and, therefore, a total absence of light results, as is marked in the figure by the large dots.

Wherever, therefore, rays of light are arranged so as to encounter one another in opposite phases of vibration, interference takes place. Thus, if we take a convex lens, of very long focus, and press it upon a flat glass by means of screws, *Fig.* 230, at the point of contact, when we inspect the instrument by reflected light a black spot will be seen, surrounded alternately by light and dark rings. These pass under the name of Newton's colored rings. When the light is homogeneous the dark rings are black, and the colored ones of the tint which is employed, but when it is common

Fig. 230

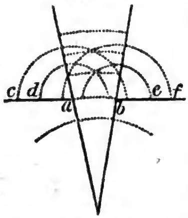


What is the effect of two whole or two half waves encountering? When does interference take place? Describe the process for forming Newton's colored rings.

white light the central black spot is surrounded by a series of colors. When the instrument is inspected by transmitted light, the colors are all complementary, and the central spot is of course white. These rings arise from the interference of the rays reflected from the anterior and posterior boundaries between the two glasses. The colors of soap-bubbles and thin plates of gypsum, are referable to the same cause.

By the diffraction of light is meant its deviation from the rectilinear path, as it passes by the edges of bodies or through apertures. It arises from the circumstance that when ethereal, or, indeed, any kind of waves impinge on a solid body, they give rise to new undulations, originating at the place of impact, and often producing interference. Thus, if a diverging beam of light passes through an aperture, *a b*, *Fig.* 231, in a plate of metal an eye placed beyond will discover a series of light and dark fringes. The cause of these has been already explained in Lecture XXXII., in which it was shown that from the points *a* and *b* new systems of undulations arise, which interfere with one another, and also with the original waves.

Fig. 231.



What is the cause of them? What is the cause of the colors of soap-bubbles and their films generally? What is meant by the diffraction of light?

LECTURE LXIII.

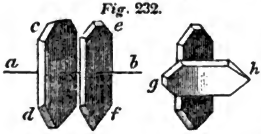
Of Polarized Light.—*Peculiarity of Polarized Light.—Illustrated by the Tourmaline.—Polarization by Reflexion.—General Law of Polarization.—Positions of no Reflexion.—Plane of Polarization.—Polarization by Refraction.—Application of the Undulatory Theory.—The Polariscope.*

When a ray of common light is allowed to fall on the surface of a piece of glass it can be equally reflected by the glass upward, downward, or laterally.

If such a ray falls upon a glass plate at an angle of 56°, and is received upon a second similar plate at a similar angle, it will be found to have obtained new properties: in some positions it can be reflected as before, in others it cannot. On examination, it is discovered that these positions are at right angles to one another.

Again: if a ray of light be caused to pass through a plate of tourmaline, *c d*, *Fig.* 232, in the direction *a b*, and be received upon a second plate, placed symmetrically with the first, it passes through both without difficulty. But if the second plate be turned a quarter round, as at *g h*, the light is totally cut off.

Fig. 232.



Considering these results, it therefore appears that we can impress upon a ray of light new properties by certain processes, and that the peculiarity consists in giving it different properties on different sides. Such a ray, therefore, is spoken of as a ray of polarized light.

When light is polarized by reflexion, the effect is only completely produced at a certain angle of incidence, which therefore passes under the name of the angle of

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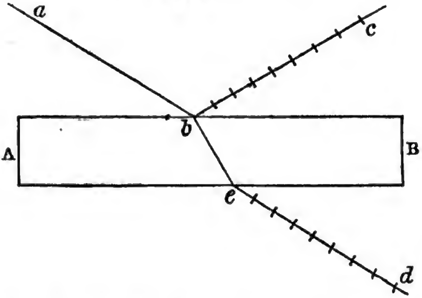
What is observed in the reflexion of ordinary light? What occurs when light which has already been reflected at 56° is attempted to be reflected again? Describe the action of a tourmaline. What is meant by polarized light? Under what circumstances does maximum polarization take place?

maximum polarization. It takes place when the reflected ray makes, with the refracted ray, an angle of 90°.

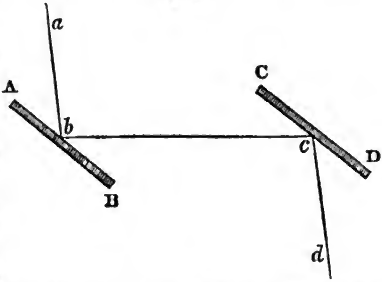
Fig. 233.



Thus, let A B, *Fig.* 233, be a plate of glass, *a b* an incident ray, which, at *b*, is partly reflected along *b c* and partly refracted along *b e*, emerging therefrom at *e d*. Now, maximum polarization ensues when *c b e* is a right angle, from which it follows that the polarizing power is connected with the refractive, the law being that "the index of refraction is the tangent of the angle of polarization."

Let A B, *Fig.* 234, be a plate of glass, on which a ray of light, *a b*, falls, and after polarization is reflected along *b c*; at *c* let it be received on a second plate, C D, similar to the former, and capable of revolving on *c b*, as it were on an axis. Let us now examine in what positions of this plate the polarized ray, *b c*, can be reflected, and in what it cannot.

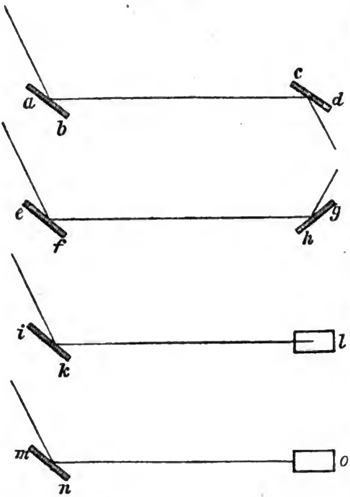
Fig. 234.



What is the law connecting refraction and polarization? What are the relative positions of the reflecting plates when the ray cannot be reflected?

Experiment at once shows that when the plane of reflexion of the first mirror coincides with the plane of reflexion of the second, the polarized ray undergoes reflexion;—but if they are at right angles to one another, it is no longer reflected. To make this clear, let *a b*, *Fig.* 235, be the first mirror, and *c d* the second, so arranged as to present their edges, as seen depicted on this page. Again: let *e f* be the first and *g h* the second, now turned half way round, but still presenting its edge, in both those positions, the planes of incidence and reflexion of both the mirrors coinciding, the ray polarized by *a b* or *e f* will be reflected. But if, as in *i k*, the second mirror, *l*, is turned so as to present its face, or, as in *m n*, it is turned at *o*, so as to present its back, in these cases, the planes of incidence and reflexion of the two mirrors being at right angles, the polarized ray can no longer be reflected. We have, therefore, two positions in which reflexion is possible, and two in which it is impossible, and these are at right angles to one another. By the *plane of polarization* we mean the plane in which the ray can be completely reflected from the second mirror.

Fig. 235.



When a ray of light falls on the surface of a transparent medium, it is divided into two portions, as has already been said, one of these being reflected and the other refracted. On examination, both these rays are found to be polarized, but they are polarized in opposite ways, or

What is the plane of polarization? In the case of a transparent medium, what is the relation between the reflected and refracted rays?

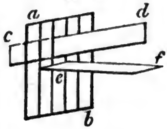
rather the plane of polarization of the refracted is at right angles to the plane of polarization of the reflected ray.

When it is required to polarize light by refraction a pile of several plates of thin glass is used, for polarization from a single surface is incomplete.

On the undulatory theory we can give a very clear account of all these phenomena. Common light originates in vibratory movements taking place in the ether; but it differs from the vibrations in the air which constitute sound in this essential particular that, while in the waves of sound the movements of the vibrating particles lie in the course of the ray, in the case of light they are transverse to it. This may be made plain by considering the wave-like motions into which a cord may be thrown by shaking it at one end, the movement being in the up-and-down or in the lateral direction, while the wave runs straight onward. The ethereal particles, therefore, vibrate transversely to the course of the ray. But then there are an infinite number of directions in which these transverse vibrations may be made: a cord may be shaken vertically or laterally, or in an infinite number of intermediate angular positions, all of which are transverse to its length.

Common light, therefore, arises in ethereal vibrations, taking place in every possible direction transverse to the path of the ray; but in polarized light the vibrations are all in one plane. Thus, in the case of the tourmaline, when a ray passes through it all the vibrations are taking place in one direction, and therefore the ray can pass through a second plate placed symmetrically with the first; but if the second be turned a quarter round the vibrations can no longer pass, just in the same way that a sheet of paper, *c d*, may be slipped through a grating, *a b*, while its plane coincides with the length of the bars; but can no longer go through when it is turned as at *e f*, a quarter round.

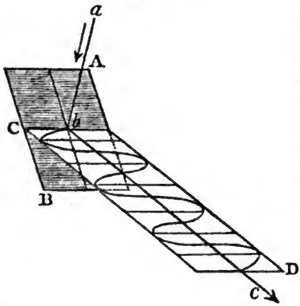
Fig. 236.



How is light to be polarized by refraction? What is light according to the undulatory theory? In what directions are the vibrations made? How may this be illustrated by a cord? In what directions are the vibrations of polarized light? How is this illustrated in *Fig.* 236?

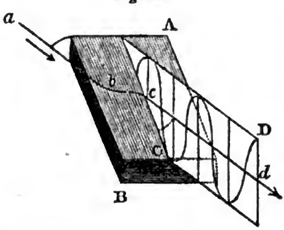
Again, in the case of polarization by reflexion, let A B, *Fig.* 237, be the mirror on which a ray of common light, *a b*, falls at the proper angle of polarization, and is reflected in a polarized condition along *b c*. C D will be the plane in which the ethereal particles vibrate after reflection, and the curve line drawn on it may represent the intensities of their vibrations.

Fig. 237.



So, too, in *Fig.* 238, we have an illustration of polarization by refraction. Let A B be a bundle of glass plates, *a b* the incident, and *c d* the polarized ray; the plane C D at right angles to the plates is the plane of polarization, and the curve drawn on it represents the intensities with which the polarized particles move.

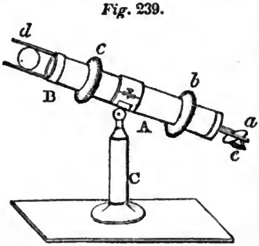
Fig 238.



In every instance the plane of polarization is perpendicular to the planes of reflexion and refraction.

The polariscope is an instrument for exhibiting the properties of polarized light. There are many different forms of it: *Fig.* 239 represents one of them. It consists of a mirror of black glass, *a*, which can be set at any suitable angle to the brass tube, A B, by means of a graduated arc, *e*; it can also be rotated on the axis of the tube B A, and the amount of that rotation read off on the

Fig. 239.



What is the illustration given as respects reflected light in *Fig.* 237? What is it for refracted light in *Fig.* 238? What is the constant position of the plane of polarization? Describe the polariscope.

graduated circle *b*. At the other end of the tube there is a second mirror of black glass, *d*, which, like *a*, can be arranged at any required angle, and likewise turned round on the axis of the brass tube, A B, the amount of its rotation being ascertained by the divided circle, *c*. Sometimes instead of this mirror of black glass, a bundle of glass plates in a suitable frame is used. The instrument is supported on a pillar, C.

The fundamental property of light polarized by reflexion may be exhibited by this instrument as follows:—Set its two mirrors, *a* and *d*, so as to receive the light which falls on them at an angle of 56°. Then, when the first, *a*, makes its reflexion in a vertical plane, the light can be reflected by *d* also in a vertical plane, upward or downward. But if *d* be turned round 90°, so as to attempt to reflect the ray to the right or left in a horizontal plane, it will be found to be impossible, the light becoming extinct and in intermediate positions; as the mirror revolves the light is of intermediate intensity.

LECTURE XLIV.

ON DOUBLE REFRACTION AND THE PRODUCTION OF COLORS IN POLARIZED LIGHT.—*Double Refraction of Iceland Spar.—Axis of the Crystal.—Crystals with two Axes.—Production of Colors in Polarized Light.—Complementary Colors Produced.—Colors Depend on the Thickness of the Film.—Symmetrical Rings and Crosses.—Colors Produced by Heat and Pressure.—Circular and Elliptical Polarization.*

BY double refraction we mean a property possessed by certain crystals, such as Iceland spar, of dividing a single incident ray into two emergent ones. Thus, let R *r* be a ray of light falling on a rhomboid of Iceland spar, A B C X, in the point *r*, it will be divided during its passage through the crystals into two rays, *r* E, *r* O, the latter of

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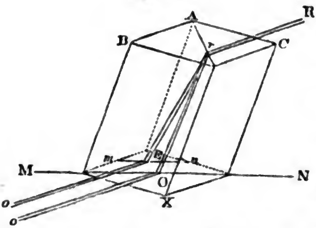
How may this instrument be used to exhibit light polarized by reflexion? What is meant by double refraction? Describe the phenomena exhibited by a crystal of Iceland spar.

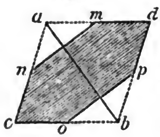
Fig. 240.



which follows the ordinary law of refraction, and therefore takes the name of the ordinary ray, the former follows a different law and is spoke of as the extraordinary ray.

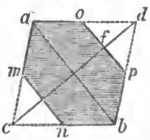
Through such a crystal objects appear double. A line, M N, on a piece of paper viewed through it is exhibited as two lines, M N, *m n*, the amount of separation depending on the thickness of the crystal. The emergent rays E *e*, O *o*, are parallel after they leave the surface X.

Fig. 241.



A line drawn through the crystal from one of its obtuse angles to the other is called the axis of the crystal, and if artificial planes be ground and polished as *n m*, *o p*, perpendicular to this axis, *a b*, *Fig.* 241, rays of light falling upon this axis or parallel to it do not undergo double refraction.

Fig. 242.



Or, if new faces, *o p*, *n m*, *Fig.* 242, be ground and polished parallel to the axis *a b*, a ray falling in the direction *d f* also remains single.

But if the refracting faces are neither at right angles nor parallel to the axis, double refraction always ensues.

While Iceland spar has only one axis of double refraction, there are other crystals, such as mica, topaz, gypsum, &c., that have two. In crystals that have but one axis there are differences. In some the extraordinary ray is inclined from the axis in others toward it when compared with the ordinary ray. The former are called *negative* crystals, the latter *positive*.

The explanation which the undulatory theory gives of this phenomenon in crystals having a principal axis is, that the ether existing in the crystal is not equally elastic

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What is the axis of the crystal? In what cases does an incident ray not undergo double refraction? What crystals have two axes of double refraction? What are negative crystals? What are positive ones?

in every direction. Undulations are therefore propagated unequally, and a division of the ray takes place, those undulations which move quickest having the less index of refraction.

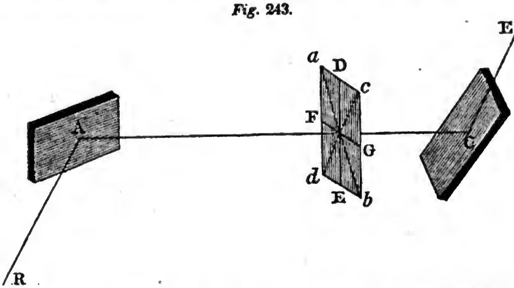
When the two rays emerging from a rhomb of Iceland spar are examined, they are both found to consist of light totally polarized, the one being polarized at right angles to the other.

We have, therefore, several different ways in which light can be polarized—by reflexion, refraction, absorption, and double refraction.

When a crystal of Iceland spar is ground to a prismatic shape, and then achromatized by a prism of glass, it forms one of the most valuable pieces of polarizing apparatus that we have. Such a prism may be used to very great advantage instead of the mirror of the apparatus, *Fig.* 239.

If a ray of polarized light is passed through a thin plate of certain crystalized bodies, such as mica or gypsum, and the light then viewed through an achromatic prism or by reflexion from the second mirror of the polarizing machine, *Fig.* 239, brilliant colors are at once

Fig. 243.



developed. Thus, let R A be a ray of light incident on the first mirror of the polariscope, A C the resulting polarized ray, and D E F G be a thin plate of gypsum or mica. If, previous to the introduction of this plate, the two mirrors A and C be crossed, or at right angles to one another, the eye placed at E will perceive no light;

What is the explanation of double refraction on the undulatory theory? What is the condition of the emergent rays? In what ways may light be polarized? Under what circumstances are colors developed by polarized light?

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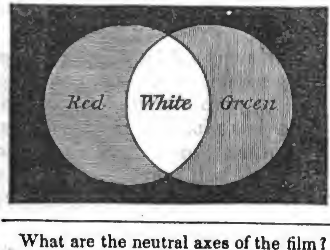
but, on the introduction of the crystal, its surface appears to be covered with brilliant colors, which change their tints according as it is inclined, or as the light passes through thicker or thinner places. On further examination it will be found that there are two lines, D E and F G, which, when either of them is parallel or perpendicular to the plane of polarization, R A C or A C E, no colors are produced. But if the plate be turned round in its own plane a single color appears, which becomes most brilliant when either of the lines *a b*, *c d*, inclined 45°, to the former ones are brought into the plane of polarization. The former lines are called the neutral, and the latter the depolarizing axes of the film.

This is what takes place so long as we suppose the two mirrors, A C, fixed; but if we make the mirror nearest to the eye revolve while the film is stationary, the phenomena are different. Let the film be of such a thickness as to give a red tint, and be fixed in such a position as to give its maximum coloration, and the eye-mirror to revolve, it will be found that the brilliancy of the color declines, and it disappears when a revolution of 45° has been accomplished; and now a pale green appears, which increases in brilliancy until 90° are reached, when it is at a maximum. Still continuing the revolution, it becomes paler, and at 135° it has ceased, and a red blush commences, which reaches its maximum at 180°; and the same system of changes is run through in passing from 180° to 360°; so that while the film revolves only one color is seen, but as the mirror revolves two appear.

If, instead of using a mirror, we use an achromatic prism, we have two images of the film at the same time, and we find that they exhibit complementary colors—that is, colors of such a tint that if they be mixed together they produce white light. This effect is represented in *Fig.* 244.

Fig. 244.

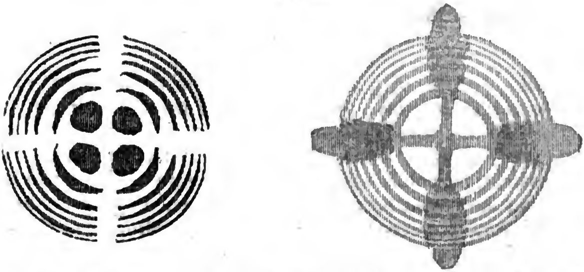


What are the neutral axes of the film? What are its depolarizing axes? What takes place when the film is stationary and the mirror revolves? What is the relation of the two resulting colors to each other?

That the particular colors which appear depend on the thickness of the films, is readily established by taking a thin wedge-shaped piece of sulphate of lime, and exposing it in the polariscope; all the different colors are then seen, arranged in stripes according to the thickness of the film.

When a slice of an uniaxial crystal cut at right angles to the axis is used instead of the films, in the foregoing experiment, very brilliant effects are produced, consisting

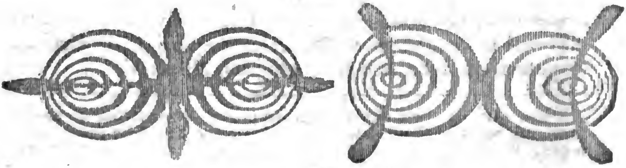
Fig. 245.



of a series of colored rings, arranged symmetrically and marked in the middle by a cross, which may either be light or dark—light if the second mirror is in the proper position to reflect the light from the first, and dark if it be at right angles thereto.

In crystals having two axes a complicated system of oval rings, originating round each axis, may be perceiv-

Fig. 246.

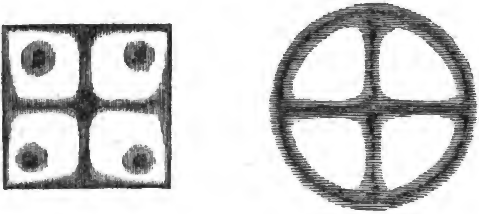


ed, intersected by a cross. *Fig.* 246, represents the appearance in a crystal of nitrate of potash; and in the same way other figures arise with different crystals.

How can it be proved that the color is determined by the thickness of the film? What phenomena are seen when slices from crystals are used? With crystals of two axes what are the results?

If transparent noncrystalized bodies are employed in these experiments, no colors whatever are perceived.

Fig. 247.



Thus, a plate of glass placed in the polariscope, gives rise to no such development; but if the structure of the glass be disturbed, either by warming it or cooling it unequally, or if it be subjected to unequal pressure from screws, then colors are at once developed. This property may, however, be rendered permanent in glass, by heating it until it becomes soft and then cooling it with rapidity.

All the phenomena here described belong to the division of plane polarization—but there are other modifications which can be impressed on light, giving rise to very remarkable and intricate results: these are designated circular, elliptical, &c., polarization. The mechanism of the motions impressed on the ether to produce these results is not difficult to comprehend; for common light, as has been stated, originates in vibrations taking place in *every* direction transverse to the ray; plane polarized light arises from vibrations in *one* direction only: and when the ethereal molecules move in circles they originate circularly polarized light, and if in ellipses, elliptical.

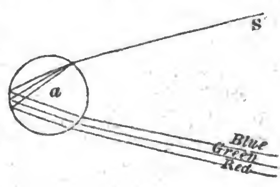
When glass is unequally warmed or cooled, or subjected to unequal pressures, what is the result? How may these effects be made permanent? What modification of the ether gives rise to plane polarization? What to circular and what to elliptical?

LECTURE XLV.

NATURAL OPTICAL PHENOMENA.—*The Rainbow.—Conditions of its Appearance.—Formation of the Inner Bow.—Formation of the Outer Bow.—The Bows are Circular Arcs.—Astronomical Refraction.—Elevation of Objects.—The Twilight.—Reflexion from the Air.—Mirages and Spectral Apparitions, and Unusual Refraction.*

THE rainbow, the most beautiful of meteorological phenomena, consists of one or more circular arcs of prismatic colors, seen when the back of the observer is turned to the sun, and rain is falling between him and a cloud, which serves as a screen on which the bow is depicted. When two arches are visible the inner one is the most brilliant, and the order of its colors is the same in which they appear in the prismatic spectrum—the red fringing its outer boundary, and the violet being within. This is called the primary bow. The secondary bow, which is the outer one, is fainter, and the colors are in the inverted order. When the sun's altitude above the horizon exceeds 42° the inner bow is not seen, and when it is more than 54° the outer is invisible. If the sun is in the horizon, both bows are semicircles, and according as his altitude is greater a less and less portion of the semicircle is visible; but from the top of a mountain bows that are larger than a semicircle may be seen.

Fig. 248.



These prismatic colors arise from reflexion and refraction of light by the drops of rain, which are of a spherical figure. In the primary bow there is one reflexion and two refractions; in the secondary there

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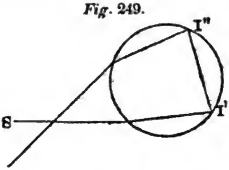
Under what circumstances does the rainbow form? Of the two bows which is the most brilliant? What is the order of the colors? What is their order in the secondary bow? What are the circumstances which determine the visibility of each bow? When are they semicircles? When more than semicircles? How is the primary bow formed?

are two reflexions and two refractions. Thus, let S, *Fig.* 248, be a ray of light, incident on a raindrop, *a;* on account of its obliquity to the surface of the drop, it will be refracted into a new path, and at the back of the drop it will undergo reflexion, and returning to the anterior face and escaping it will be again refracted, giving rise to violet and red and the intermediate prismatic colors between, constituting a complete spectrum; and as the drops of rain are innumerable the observer will see innumerable spectra arranged together so as to form a circular arc.

Fig. 249.



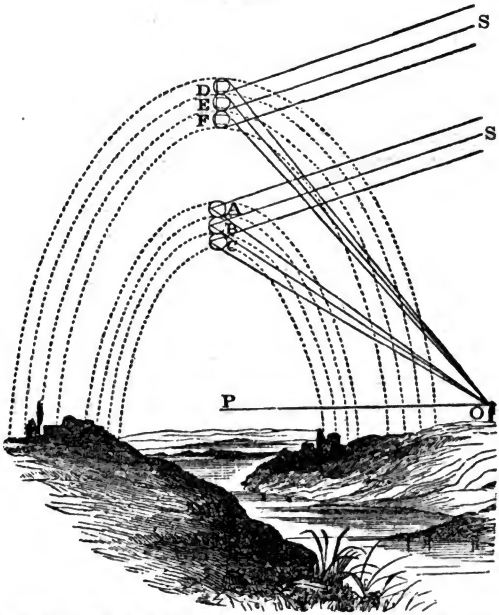
The secondary rainbow arises from two refractions and two reflexions of the rays. Thus, let the ray S, *Fig.* 249, enter at the bottom of the drop, it passes in the direction toward I′ after having undergone refraction at the front; from I′ it moves to I″, where it is a second time reflected, and then emerges in front, undergoing refraction and dispersion again. For the same reason as in the other case, prismatic spectra are seen arranged together in a circular arc and form a bow.

In *Fig.* 250, let O be the spectator and O P a line drawn from his eye to the center of the bows. Then rays of the sun, S S, falling on the drops A B C, will produce the inner bow, and falling on D E F, the outer bow, the former by one and the latter by two reflexions. The drop A reflects the red, B the yellow, and C the blue rays to the eye; and in the case of the outer bow, F the red, E the yellow, and D the blue. And as the color perceived is entirely dependent on the angle under which the ray enters the eye, as in the case of the interior bow, the blue entering at the angle C O P, the yellow at the larger angle B O P, and the red and the largest A O P, we see the cause why the bows are circular arcs. For out of the innumerable drops of rain which compose the shower, those only can reflect to the eye a red color which make the same angle, A O P, that A does with the line O P, and these must necessarily be arranged in

What are the conditions for the formation of the secondary bow? Why are both bows circular arcs?

a circle of which the center is P. And the same reasoning applies for the yellow, the blue, or any other ray as

Fig. 250.



well as the red, and also for the outer as well as the inner bow.

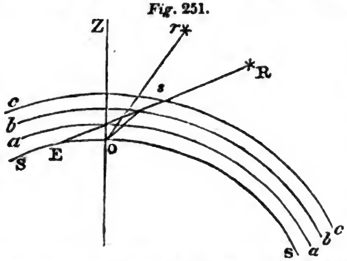
Another interesting natural phenomenon connected with the refraction of light is what is called "astronomical refraction," arising from the action of the atmosphere on the rays of light. It is this which so powerfully disturbs the positions of the heavenly bodies, making them appear higher above the horizon than they really are, and changes the circular form of the sun and moon to an oval shape. It also aids in giving rise to the twilight.

Let O be the position of an observer on the earth, Z,

What is the cause of astronomical refraction?

Fig. 251, will be his zenith, and let R be any star, the rays from which come, of course, in straight lines, such as R E. Now, when such a ray impinges on the atmosphere at *s*, it is refracted, and deviates from its rectilinear course. At first this refraction is feeble, but the atmosphere continually increases in density as we descend in it, and therefore the deviation of the ray from its original path, R E, becomes continually greater. It follows a curvilinear line, and finally enters the eye of the observer at O. This may perhaps be more clearly understood by supposing the concentric circles, *a a*, *b b*, *c c*, represented in the figure, to stand for concentric shells of air of the same density, the ray at its entry on the first becomes refracted, and pursues a new course to the second. Here the same thing again takes place, and so with the third and other ones successively. But these abrupt changes do not occur in the atmosphere, which does not change its density from stratum to stratum abruptly, but gradually and continually. The resulting path of the ray is, therefore, not a broken line, but a continuous curve.

Fig. 251.



Now, it is a law of vision that the mind judges of the position of an object as being in the direction in which the ray by which it is seen enters the eye. Consequently the star, R, which emits the ray we have under consideration, will be seen in the direction, O *r*—that being the direction in which the ray entered the eye—and, therefore, the effect of astronomical refraction is to elevate a star or other object above the horizon to a higher apparent position than that which it actually occupies.

Astronomical refraction is greater according as the object is nearer the horizon, becoming less as the altitude

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Trace the path of a ray of light which impinges obliquely on the atmosphere. Why is it of a curvilinear figure? How does the mind judge of the position of an object? What is, therefore, the effect of astronomical refraction? What is the difference in this respect between an object in the horizon and one in the zenith?

increases, and ceasing in the zenith. An object seen in the zenith is therefore in its true position.

On these principles, the figure of the sun and moon, when in the horizon, changes to an oval shape; for the lower edge being more acted upon than the upper, is therefore relatively lifted up, and those objects made less in their vertical dimensions than in their horizontal.

Even when an object is below the horizon it may be so much elevated as to be brought into view; for just in the same way that a star, R, is elevated to *r*, so may one beneath the horizon be elevated even to a greater extent, because refraction increases as we descend to the horizon. Stars, therefore, are visible before they have actually risen, and continue in sight after they have actually set. They are thus lifted out of their true position when in the horizon about thirty-three minutes. In the books on astronomy tables are given which represent the amount of refraction for any altitude.

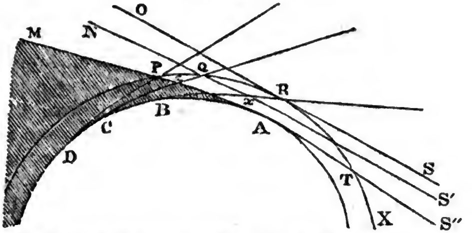
What has been here said in relation to a star holds also for the sun; which, therefore, is made apparently to rise sooner and set later than what is the case in reality. From this arises the important result that the day is prolonged. In temperate climates, this lengthening of the day extends only to a few minutes, in the polar regions the *day* is made longer by a *month*. And it is for this cause, too, that the morning does not suddenly break just at the moment the sun appears in the horizon, and the night set in the instant he sinks; but the light gradually fades away, as a twilight, the rays being bent from their path, and the scattering ones which fall on the top of the atmosphere brought in curved directions down to the lower parts.

The phenomenon of twilight is not, however, wholly due to refraction. The reflecting action of the particles of the air is also greatly concerned in producing it. The manner in which this takes place is shown in *Fig.* 252, where A B C D represents the earth, T R P the atmosphere, and S O, S′ N, S″ A rays of the sun passing through it. To an observer, at the point A, the sun, at S″, is just

Why is the figure of the sun or moon oval in the horizon? What is to be observed as respects the rising and setting of stars? What effect has the refraction of the air in producing twilight? How is it that the reflective power of the air aids in this effect?

set, but the whole hemisphere above him, P R T, being his sky, reflects the rays which are still falling upon it, and gives him twilight. To an observer, at B, the sun

Fig. 252.



has been set for some time, and he is in the earth's shadow, but that part of his sky which is included between P Q R x is still receiving sun-rays, and reflecting them to him. To an observer at C, the illuminated portion of the sky has decreased to P Q x. His twilight, therefore, has nearly gone. To an observer at D, whose horizon is bounded by the line D P, the sky is entirely dark, no rays from the sun falling on it. It is, therefore, night.

The action of the atmosphere sometimes gives rise to curious spectral appearances—such as inverted images, looming, and the mirage. The latter, which often occurs on hot sandy plains, was frequently seen by the French during their expedition to Egypt, giving rise to a deceptive appearance of great lakes of water resting on the sands. It appears to be due to the partial rarefaction of the lower strata of air through the heat of the surface on which they rest, so that rays of light are made to pass in a curvilinear path, and enter the eye. In the same way at sea, inverted images of ships floating in the air are often discovered.

Thus, "On the 1st of August, 1798, Dr. Vince observed at Ramsgate a ship, which appeared, as at A, *Fig*. 253, the topmast being the only part of it seen above the horizon. An inverted image of it was seen at B, immediately above the real ship, at A, and an erect image at C, both of them being complete and well defined. The sea was

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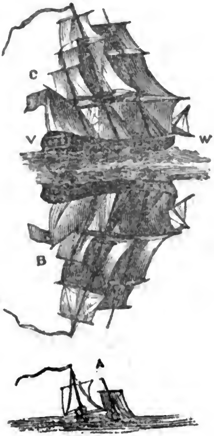
Describe this effect in the four positions, A, B, C, D of *Fig*. 252. Mention some remarkable appearances due to unusual refraction and reflexion of the air.

distinctly seen between them, as at V W. As the ship rose to the horizon, the image, C, gradually disappeared; and, while this was going on, the image B, descended, but the mainmast of B did not meet the mainmast of A. The two images, B C, were perfectly visible when the whole ship was actually below the horizon."

Fig. 253.



These singular appearances, which have often given rise to superstitious legends, may be imitated artificially. Thus, if we take a long mass of hot iron, and, looking along the upper surface of it at an object not too distant, we shall see not only the object itself, but also an inverted image of it below, the second image being caused by the refraction of the rays of light as they pass through the stratum of hot air, as is the case of the mirage.

The trembling which distant objects exhibit, more especially when they are seen across a heated surface, is, in like manner, due to unusual aud irregular refraction taking place in the air.

LECTURE XLVI.

THE ORGAN OF VISION.—*The Three Parts of the Eye.—Description of the Eye of Man.—Uses of the Accessory Apparatus.—Optical Action of the Eye.—Short and Long-Sightedness.—Spectacles.—Erect and Double Vision.—Peculiarities of Vision.—Physiological Colors.*

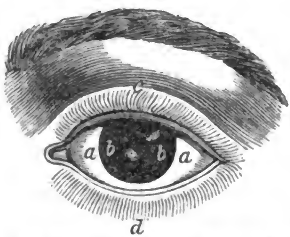
ALMOST all animals possess some mechanism by which they are rendered sensible of the presence of light. In some of the lower orders, perhaps, nothing more than a diffused sensibility exists, without there being any special

How may the mirage be imitated? How is it known that the lowest animals are sensible to light?

organ adapted for the purpose. Thus, many animalcules are seen to collect on that side of the liquid in which they live on which the sun is shining, and others avoid the light. But in all the higher tribes of life there is a special mechanism, which depends for its action on optical laws—it is the eye.

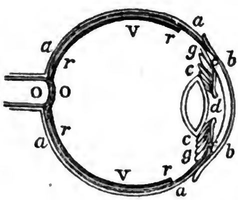
This organ essentially consists of three different parts—an optical portion, which is the eye, strictly speaking; a nervous portion, which transmits the impressions gathered by the former to the brain; and an accessory portion, which has the duty of keeping the eye in a proper working state and defending it from injury.

Fig. 254.



In man the eye-ball is nearly of a spherical figure, being about an inch in diameter. As seen in front, between the two eyelids, *d c*, *Fig.* 254, it exhibits a white portion of a porcelain-like aspect, *a a;* a colored circular part, *b b*, which continually changes in width, called *the iris;* and a central black portion, which is *the pupil.*

Fig. 255.



When it is removed from the orbit or socket in which it is placed, and dissected, the eye is found to consist of several coats. The white portion seen anteriorly at *a a* extends all round. It is very tough and resisting, and by its mechanical qualities serves to support the more delicate parts within, and also to give insertion for the attachment of certain muscles which roll the eye-ball, and direct it to any object. This coat passes under the name of *the sclerotic.* It is represented in *Fig.* 255, at *a a a a.* In its front there is a circular aperture, into which a transparent portion, *b b*, resembling in shape a watch-glass, is inserted. This

Of how many parts does the eye consist? What are the offices of these parts? What is the figure and size of the eye in man? What is the iris, the pupil, and the sclerotic coat?

This is called *the cornea.* It projects somewhat beyond the general curve of the sclerotic, as seen at *b b*, in the figure, and with the sclerotic completes the outer coat of the eye.

The interior surface of the sclerotic is lined with a coat which seems to be almost entirely made up of blood-vessels, little arteries and veins, which, by their internetting, cross one another in every possible direction. It is called *the choroid* coat: it extends like the sclerotic as far as the cornea. Its interior surface is thickly covered with a slimy pigment of a black color, hence called *pigmentum nigrum.* Over this is laid a very delicate serous sheet, which passes under the name of *Jacob's membrane*, and the *optic nerve*, O O, coming from the brain perforates the sclerotic and choroid coats, and spreads itself out on the interior surface as *the retina*, *r r r r*. The optic nerves of the opposite eyes decussate one another on their passage to the brain.

These, therefore, are the coats of which the eye is composed. Let us examine now its internal structure. Behind the cornea, *b b*, there is suspended a circular diaphragm, *e f*, black behind and of different colors in different individuals in front. This is *the iris.* Its color is, in some measure, connected with the color of the hair. The central opening in it, *d*, is *the pupil*, and immediately behind the pupil, suspended by the *ciliary processes*, *g g*, is the *crystaline lens*, *c c*—a double convex lens. All the space between the anterior of the lens and the cornea is filled with a watery fluid, which is the *aqueous humor;* that portion which is in front of the iris is called the *anterior chamber*, and that behind it the *posterior.* The rest of the space of the eye, bounded by the crystaline lens in front and the retina all round, is filled with the *vitreous humor*, V V.

With respect to the accessory parts, they consist chiefly of the *eyelids*, which serve to wipe the face of the eye and protect it from accidents and dust; the *lachrymal apparatus*, which serves to wash it with *tears*, so as to keep it

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What is the cornea? What are the choroid coat, pigmentum nigrum, and Jacob's membrane? What are the optic nerve and retina? What is the position of the iris? How is the lens supported? Where is the aqueous humor? Where the vitreous? What are the two chambers of the eye? What are the accessory parts and their uses?

continually brilliant; and the *muscles* requisite to direct it upon any point.

Of the nervous part of the eye, so far as its functions are concerned, but little is known—the retina receives the impressions of the light, and they are conveyed along the optic nerve to the brain.

Now as respects the optical action of the eye, it is obviously nothing more than that of a convex lens, to which, indeed, its structure actually corresponds: and as in the focus of such a convex lens objects form images, so by the conjoint action of the cornea and crystaline, the images of the things to which the eye is directed form at the proper focal distance behind—that is, upon the retina. Distinct vision only takes place when the cornea and the lens have such convexities as to bring the images exactly upon the retina.

In early life it sometimes happens that the curvature of these bodies is too great, and the rays converging too rapidly, form their images before they have reached the posterior part of the eye, giving rise to the defect known as short-sightedness—a defect which may be remedied by putting in front of the cornea a concave glass lens of such concavity as just to compensate for the excess of the convexity of the eye.

In old age, on the contrary, the cornea and the lens become somewhat flattened, and they cannot converge the rays soon enough to form images at the proper distance behind. This long-sightedness may be remedied by putting in front of the cornea a convex lens, so as to help it in its action.

Concave or convex lenses thus used in front of the eyes constitute spectacles. It is believed that this application was first made by Roger Bacon, and it unquestionably constitutes one of the most noble contributions which science has ever made to man. It has given sight to millions who would otherwise have been blind.

As the image which is formed by a convex lens is inverted as respects its object, so must the images which form at the bottom of the eye. It has, therefore, been a

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What is the duty of the retina, and what that of the optic nerve? To what optical contrivance is the eye analogous? When does distinct vision take place? What is the cause of short-sightedness, and what is its cure? What is the cause of long-sightedness, and its cure?

question among optical writers, why we see objects in their natural position, and also why we do not see double, inasmuch as we have two eyes. Various explanations of these facts have been offered, chiefly founded upon optical principles. None, however, appear to have given general satisfaction, and in reality the true explanation, I believe, will be found not in the optical, but in the nervous part of the visual organ. It is no more remarkable that we see single, having two eyes, than that we hear single, having two ears. It is the simultaneous arrival in the brain, that gives rise out of two impressions to one perception, and accordingly, when we disturb the action of one of the eyes by pressing on it, we at once see double.

Among the peculiarities of vision it may be mentioned, that for an object to be seen it must be of certain magnitude, and remain on the retina a sufficient length of time; and, for distinct vision, must not be nearer than a certain distance, as eight or ten inches. This distance of distinct vision varies somewhat with different persons. The eye, too, cannot bear too brilliant a light, nor can it distinguish when the rays are too feeble; though it is wonderful to what an extent in this respect its powers range. We can read a book by the light of the sun or the moon; yet the one is a quarter of a million times more brilliant than the other. Luminous impressions made on the retina last for a certain space of time, varying from one third to one sixth of a second. For this reason, when a stick with a spark of fire at the end is turned rapidly round, it gives rise to an apparent circle of light.

By accidental or physiological colors we mean such as are observed for a short time depicted on surfaces, and then vanishing away. Thus, if a person looks steadfastly at a sheet of paper strongly illuminated by the sun, and then closes his eyes, he will see a black surface corresponding to the paper. So if a red wafer be put on a sheet of paper in the sun, and the eye suddenly turned on a white wall, a green image of the wafer will be seen. Spectral illusions in the same way often arise—thus, when

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Is there any thing remarkable respecting erect and double vision? What peculiarities respecting vision may be remarked? What is the distance of distinct vision? To what range of intensity of light can the eye adapt itself? Why does a lighted stick turned round rapidly give rise to the appearance of a circle of fire? What is meant by accidental colors?

we awake in the morning, if our eyes are turned at once to a window brightly illuminated, on shutting them again we shall see a visionary picture of every portion of the window, which after a time fades away.

LECTURE XLVII.

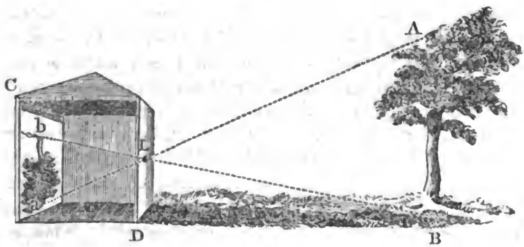
Of Optical Instruments.—*The Common Camera Obscura.—The Portable Camera.—The Single Microscope.—The Compound Microscope.—Chromatic and Spherical Aberration.—The Magic Lantern.—The Solar Microscope.—The Oxyhydrogen Microscope.*

In this and the next Lecture I shall describe the more important optical instruments. These, in their external appearance, and also in their principles, differ very much according to the taste or ideas of the artist. The descriptions here given will be limited to such as are of a simple kind.

The Camera Obscura, or dark chamber, originally consisted of nothing more than a double convex lens, of a foot or two in focus, fixed in the shutter of a dark room. Opposite the lens and at its focal distance, a white sheet received the images. These represent whatever is in front of the lens, giving a beautiful picture of the stationary and movable objects in their proper relation of light and shadow, and also in their proper colors.

In point of fact, a lens is not required: for, if into a

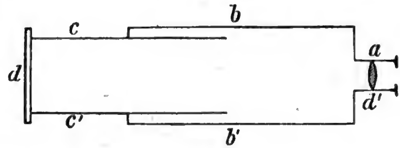
Fig. 256.



What was the original form of the camera obscura?

dark chamber. C D, *Fig.* 256, rays are admitted through a small aperture, L, an inverted image will be formed on a white screen at the back of the chamber, of whatever objects are in front. Thus the object, A B, gives the inverted image, b a. These images are, however, dim, owing to the small amount of light which can be admitted through the hole. The use of a double convex lens permits us to have a much larger aperture, and the images are correspondingly brighter.

Fig. 257.



The portable camera obscura consists of an achromatic double convex lens, *a a'*, set in a brass mounting in the front of a box consisting of two parts, of which *c c'* slides in the wider one, *b b'*. The total length of the box is adjusted to suit the focal distance of the lens. In the back of the part, *c c'*, there is a square piece of ground glass, *d*, which receives the images of the objects to which the lens is directed, and by sliding the movable part in or out the ground glass can be brought to the precise focus. The interior of the box and brass piece, *a a'*, is blackened all over to extinguish any stray light.

The images of the camera are, of course, inverted, but they can be seen in their proper position by receiving them on a looking-glass, placed so as to reflect them upward to the eye. Objects that are near, compared with objects that are distant, require the back of the box to be drawn out, because the foci are farther off. Moreover, those that are near the edges are indistinct, while the central ones are sharp and perfect. This arises from the circumstance that the edges of the ground glass are farther from the lens than the central portion, and, therefore, out of focus.

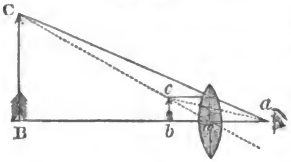
OF MICROSCOPES.

The single microscope.—When a convex lens is placed

Is it necessary to have a lens? What advantage arises from the use of one? Describe the portable camera obscura. Why does the focal distance vary for different objects? Why are the images on the edges indistinct while the central ones are sharp?

between the eye and an object situated a little nearer than its focal distance, a magnified and erect image will be seen.

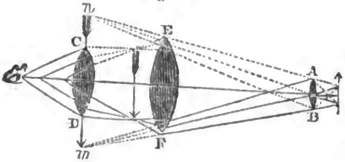
Fig. 258.



The single microscope consists of such a lens, *m*, *Fig.* 258, the object, *b c*, being on one side and the eye, *a*, at the other, a magnified and erect image, B C, is seen. The linear magnifying power of such a lens is found by dividing the distance of distinct vision by its focal length.

The compound microscope commonly consists of three lenses, A B, E F, C D, *Fig.* 259; A B being the object-glass, E F the field-glass, and C D the eye-glass. Beyond the object-glass is placed the object, at a distance somewhat greater than the focal length; a magnified image is, therefore, produced, and this being viewed by the eye-glass is still further magnified, and, of course, seen in an inverted position. The use of the field-glass is to intercept the extreme pencils of light, *n m*, coming from the object-glass, which would otherwise not have fallen on the eye-lens. It therefore increases the field of view, and hence its name.

Fig. 259.



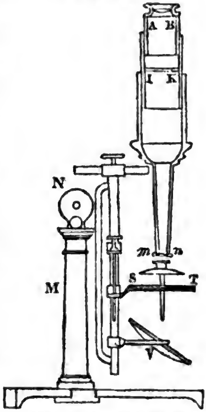
In this instrument the object-glass has a very short focus, the eye-glass one that is much larger; and the field-glass and the eye-glass can be so arranged as to neutralize chromatic aberration.

To determine directly the magnifying power of this instrument, an object, the length of which is known, is placed before it. Then one eye being applied to the instrument, with the other we look at a pair of compasses, the points of which are to be opened until they subtend a space equal to that under which the object appears. This space being divided by the known length of the object, gives the magnifying power.

Describe the single microscope. How is its magnifying power found? Describe the compound microscope. What is the use of the field lens? How may its magnifying power be found?

In *Fig*. 260, we have a representation of the compound microscope, as commonly made. A B is a sliding brass tube, which bears the eye-glass; *m n* is the object-glass; I K the field-glass; S T a stage for carrying the objects. It can be moved to the proper focal distance by means of a pinion. At V there is a mirror which reflects the light of a lamp or the sky upward, to illuminate the object. The body of the microscope is supported on the pillar M, and it can be turned into the horizontal or any oblique position to suit the observer, by a joint, N. To the better kind of instruments micrometers are attached, for the purpose of determining the dimensions of objects. These are sometimes nothing more than a piece of glass, on which fine lines have been drawn with a diamond, forming divisions the value of which is known. Such a plate may be placed either immediately beneath the object or at the diaphragm, which is between the two lenses.

Fig. 260.



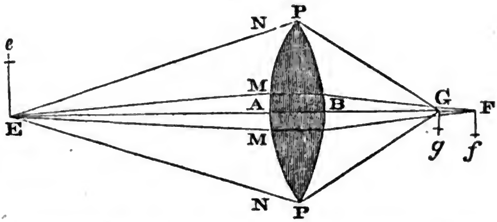
In microscopes the defective action of lenses, known as chromatic aberration, and described in Lecture XLI., interferes, and, by imparting prismatic colors to the edges of objects, tends to make them indistinct. To overcome this difficulty, achromatic object-glasses are used in the finer kinds of instruments.

Besides chromatic aberration, there is another defect to which lenses are subject. It arises from their spherical figure, and hence is designated *spherical aberration*. Let P P, *Fig*. 261, be a convex lens, on which rays, E P, E P, E M, E M, E A, from any object, E *e*, are incident, it is obvious that the principal ray, E A, will pass on, through B, to F without undergoing refraction. Now, rays which are near to this, as E M, E M, converge by the action of the lens to a focus at F; but those which are more distant, and fall near the edges of the lens, as

Describe the parts of the compound microscope represented in *Fig*. 260. What kind of micrometers may be used? What are the effects of chromatic and spherical aberration?

E N, E N, converge more rapidly, and come to a focus at G. Thus, images, F *f*, G *g*, are formed by the extreme rays, and an intermediate series of them by the

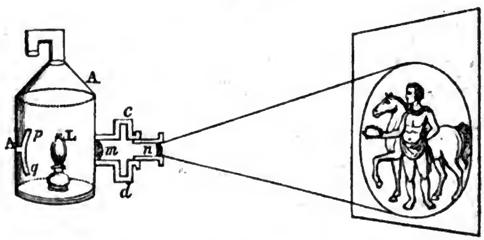
Fig. 261.



intermediate rays, the whole arising from the peculiarity of figure of the lens. It is, indeed, the same defect as that to which spherical mirrors are liable, as explained in Lecture XXXVII; and hence, to obtain perfect action with a spherical lens, as with a spherical mirror, its aperture must be limited.

The Magic Lantern consists of a metallic lantern,

Fig. 262.



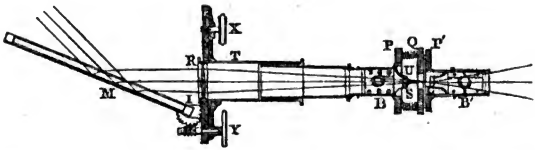
A A′ *Fig*. 262, in front of which two lenses are placed. One of these, *m*, is the illuminating lens, the other, *n*, the magnifier. A powerful Argand lamp is placed at L, and behind it a concave mirror, *p q*. In the space between the two lenses the tube is widened *c d*, or such an arrangement made that slips of glass, on which various figures are painted, can be introduced. The action of the instrument is very simple. The mirror and the lens *m*

Describe the magic lantern. What is the use of its condensing lens and mirror?

illuminate the drawing as highly as possible; for the lamp being placed in their foci, they throw a brilliant light upon it, and the magnifying lens, *n*, which can slide in its tube a little backward and forward, is placed in such a position as to throw a highly magnified image of the drawing upon a screen, several feet off, the precise focal distance being adjusted by sliding the lens. As it is an inverted image which forms, it is, of course, necessary to put the drawing in the slide, *c d*, upside down, so as to have their images in the natural position. Various amusing slides are prepared by the instrument-makers, some representing bodies or parts in motion. The figures require to be painted in colors that are quite transparent.

THE SOLAR MICROSCOPE.—This instrument, like the

Fig. 263.



magic lantern, consists of two parts—one for illuminating the object highly, and the other for magnifying it. It consists of a brass plate, which can be fastened to an aperture in the shutter of a dark room, into which a beam of the sun may be directed by means of a plane mirror. In *Fig.* 263, M is the mirror, to which movement in any direction may be given by the two buttons, X and Y, that rays from the sun may be reflected horizontally into the room. They pass through a large convex lens, R, and are con-converged by it; they again impinge on a second lens, U S, which concentrates them to a focus, the precise point of which may be adjusted by sliding the lens to the proper position by the button B. P P′ is in apparatus, consisting of two fixed plates, with a movable one, Q, between them, Q being pressed against P′ by means of spiral springs. This apparatus is for the purpose of supporting the various objects which are held by the pressure

Why must the slider be put in upside down? What are the two parts of the solar microscope? Describe the instrument as represented in *Fig.* 263.

of Q against P′. Immediately beyond this, at L, is the magnifying lens, or object-glass, which can be brought to the proper position from the highly illuminated object by means of the button B′, and the magnified image resulting is then thrown on a screen at a distance.

The solar microscope has the great advantage of exhibiting objects to a number of persons at the same time.

In principle, the oxyhydrogen microscope is the same as the foregoing, only, instead of employing the light of the sun, the rays of a fragment of lime ignited in the flame of a oxyhydrogen blow-pipe are used. These rays are converged on the object, and serve to illuminate it. The advantage the instrument has over the solar microscope is that it can be used at night and on cloudy days.

LECTURE XLVIII.

OF TELESCOPES.—*Refracting and Reflecting Telescopes.—Galileo's Telescope.—The Astronomical Telescope.—The Terrestrial.—Of Reflecting Telescopes.—Herschel's Newton's, Gregory's.—Determination of their Magnifying Powers.—The Achromatic Telescope.*

THE telescope is an instrument which, in principle, resembles the microscope, both being to exhibit objects to us under a larger visual angle. The microscope does this for objects near at hand, the telescope for those that are at a distance.

Telescopes are of two kinds, refracting and reflecting. Each consists essentially of two parts, the object-glass or objective, and the eye-piece. In the former, the objective is a lens, in the latter it is a concave mirror.

The distinctness of objects through telescopes is necessarily connected with the brilliancy of the images they give, and this, among other things, depends on the size of the objective.

What advantage has the solar microscope over other forms of instrument? What is the oxyhydrogen microscope? What is the telescope? Of how many kinds are telescopes? What are their essential parts? What is the objective in the refracting and reflecting telescope, respectively? On what does the brilliancy depend?

There are three kinds of refracting telescopes:—1st, Galileo's; 2d, the astronomical; 3d, the terrestrial.

GALILEO'S TELESCOPE, which is represented in *Fig.*

Fig. 264.

264, consists of a convex lens, L N, which is the objective, and a concave eye-glass, E E. Let O B be a distant object, the rays from which are received upon L N, and by it would be brought to a focus, and give the image, M I; but, before they reach this point, they are intercepted by the concave eye-glass, E E, which makes them diverge, as represented at H K, and give an erect image, *i m*.

This form of telescope has an advantage in the erect position of its image, which is usually presented with great clearness. Its field of view, by reason of the divergence of the rays through the eye-glass, is limited. When made on a small scale, it constitutes the common opera-glass.

THE ASTRONOMICAL TELESCOPE differs from the former

Fig. 265.

in having for its eye-piece a convex lens of short focus compared with that of the object-lens. In this, as in the former instance, the office of the objective is to give an image, and the eye-piece magnifies it precisely on the same principle that it would magnify any object. In *Fig.* 265, L N is the objective, and E E the eye-glass; the rays from a distant object, O B, are converged so as to give a focal image, M I. This being viewed through the eye-lens, E E, is magnified, and is also inverted. The magnifying power of the telescope is found by di-

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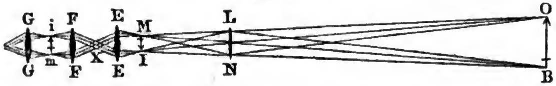
How many kinds of refracting telescopes are there? Describe Galileo's telescope. Why has it so small a field of view? What are the essential parts of the astronomical telescope? Why does it invert?

viding the focal length of the objective by that of the eye-lens.

This telescope, of course, inverts, and therefore is not well adapted for terrestrial objects; but for celestial ones it answers very well.

THE TERRESTRIAL TELESCOPE consists of an object-

Fig. 266.



lens, like the foregoing, but in its eye-piece are three lenses of equal focal lengths. The combination is represented in *Fig.* 266, in which L N is the object lens, and E E, F F, G G the eye-lenses, placed at distances from each other equal to double their focal length. The progress of the rays through the object-lens and the first eye-glass to X is the same as in the astronomical telescope; but, after crossing at X, they are received on the second eye-lens, which gives an erect image of them, at *i m*, which is viewed, therefore, in the erect position by the last eye-lens, G G.

As the distance at which the image forms from the object-lens is dependent on the actual distance of the object itself, one which is near giving its image farther off than one which is distant, it is necessary to have the means of adjusting the eye-piece, so as to bring it to the proper distance from the image, M I. The object-lens is therefore put in a tube longer than its own focus, and in this a smaller tube, bearing the three eye-lenses, immovably fixed, slides backward and forward; this tube is drawn out until distinct vision of the object is attained.

REFLECTING TELESCOPES are of several different kinds. They have received names from their inventors.

HERSCHEL'S TELESCOPE consists of a metallic concave mirror, set in a tube in a position inclined to the axis. It of course gives an inverted image of the object at its focus, and the inclination is so managed as to have the image form at the side of the tube. There it is viewed by

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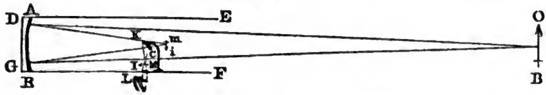
How is its magnifying power found? Describe the terrestrial telescope. What is the action of its three eye-lenses? Why must there be means of sliding the eye-piece? How are reflecting telescopes designated? Describe Herschel's telescope.

an eye-lens, which shows it magnified and inverted. The back of the observer is turned to the object, and the inclination of the mirror is for the purpose of avoiding obstruction of the light by the head.

NEWTON'S TELESCOPE consists of a concave mirror, A R, *Fig.* 267, with its axis parallel to that of the tube, D E

Fig. 267



F G, in which it is set. The rays reflected from it are intercepted by a plane mirror, C K, placed at an angle of 45°, on a sliding support, m. They are, therefore, reflected toward the side of the tube, the image, i m, forming at I M, an eye-glass at L magnifies it.

THE GREGORIAN TELESCOPE has a concave mirror, A R, *Fig.* 268, with an aperture, L, in its center. The rays

Fig. 268.

from a distant object, O B, give, as before, an inverted image, M I. They are then received on a small concave mirror, K C, placed fronting the great one. This gives an erect image, which is magnified by the eye-lens, P.

The magnifying power of any of these instruments may be roughly estimated by looking at an object through them with one eye, and directly at it with the other, and comparing the relative magnitude of the two images. In Herschel's telescope the back of the observer is toward the object, in Newton's his side, but in Gregory's he looks directly at it. The latter is, therefore, by far the most agreeable instrument to use. The largest telescopes hitherto constructed are upon the plan of Herschel and Newton.

When Sir Isaac Newton discovered the compound nature of light, by prismatic analysis, he came to the con-

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In what position does the observer stand? Describe Newton's telescope Describe the Gregorian telescope. How may the magnifying power of these instruments be ascertained?

clusion that the refracting telescope could never be a perfect instrument, because it appeared impossible to form an image by a convex lens, without its being colored on the edges by the dispersion of light. He therefore turned his attention to the reflecting telescope, and invented the one which bears his name. He even manufactured one with his own hands. It is still preserved in the cabinet of the Royal Society of London.

But after it was discovered that refraction without dispersion can be effected, and that lenses can be made to form colorless images in their foci, the principle was at once applied to the telescope; and hence originated that most valuable astronomical instrument, the achromatic telescope.

In this the object-glass is of course compound, consisting, as represented in *Fig*. 269, of one crown and one

Fig. 269.

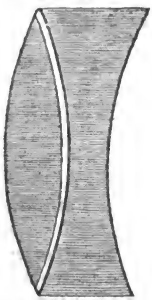
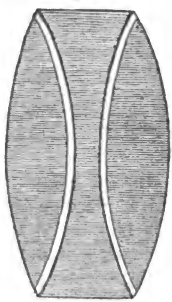


Fig. 270.



flint-glass lens, or as represented in *Fig*. 270, of one flint and two crown-glass lenses. The principle of its action has been described in Lecture XLI. The great expense of these instruments arises chiefly from the costliness of the flint-glass, for it has hitherto been found difficult to obtain it in masses of large size, perfectly free from veins or other imperfections. Nevertheless, there are instruments which have been constructed in Germany, with an aperture of thirteen inches. Some of these are mounted on

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What was it that led to the adoption of the reflecting telescope? On what does the achromatic telescope depend? Of what parts are the double and triple object-glasses composed? What is the cause of the costliness of these instruments?

a frame, connected with a clock movement, so that when the telescope is turned to a star it is steadily kept in the center of the field of view, notwithstanding the motion of the earth on her axis. Several large instruments of this description are now in the different observatories of the United States.

THE PROPERTIES OF HEAT.

THERMOTICS.

LECTURE XLIX.

THE PROPERTIES OF HEAT.—*Relations of Light and Heat.—Mode of Determining the Amount of Heat.—The Mercurial Thermometer.—Its Fixed Points.—Fahrenheit's, Centigrade, Reaumur's Thermometers.—The Gas Thermometer.—Differential Thermometer.—Solid Thermometers.—Comparative Expansion of Gases, Liquids, and Solids.*

WHATEVER may be the true cause of light, whether it be undulations in an ethereal medium, or particles emitted with great velocity by shining bodies, observation has clearly proved that heat is closely allied to it.

When a body is brought to a very high temperature, and then allowed to cool in a dark place, though it might be white-hot at first it very soon becomes invisible, losing its light apparently in the same way that its loses its heat. And we shall hereafter find the rays of heat which thus escape from it may be reflected, refracted, inflected, and polarized, just as though they were rays of light.

In its general relations heat is of the utmost importance in the system of nature. The existence of life, both vegetable and animal, is dependent on it; it determines the dimensions of all objects, regulates the form they assume, and is more or less concerned in every chemical change that takes place.

Every object to which we have access possesses a certain amount of heat, and so long as it remains at common

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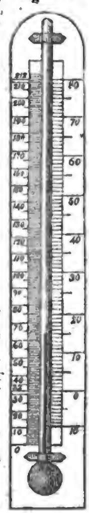
What is observed during the cooling of bodies? Why are the relations of heat of such philosophical importance?

temperatures, may be touched without pain; but if a larger quantity of heat is given to it, it assumes qualities that are wholly new, and if touched it burns.

To determine, therefore, with precision the quantity of heat which is present in a body when it exhibits any particular phenomenon, it is necessary that we should be furnished with some means of effecting its measurement. Instruments intended for this purpose are called thermometers.

Of thermometers we have several different kinds. Some are made of solid substances, others of liquids, and others of gases. With a few exceptions, they all depend on the same principle—the expansion which ensues in all bodies as their temperature rises.

Fig. 271



Of these the mercurial thermometer is the most common, and for the purpose of science the most generally available. It consists of a glass tube, *Fig.* 271, with a bulb on its lower extremity. The entire bulb and part of the tube are filled with quicksilver, and the rest of the tube, the extremity of which is closed, contains a vacuum. This glass portion is fastened in an appropriate manner, upon a scale of ivory or metal, which bears divisions, and the thermometer is said to be at that particular degree against which its quicksilver stands on the scale.

If we take the bulb of such an instrument in the hand, the quicksilver immediately begins to rise in the tube, and finally is stationary at some particular degree, generally the 98th in our thermometers. We therefore say the temperature of the hand is 98 degrees.

In effecting a measure of any kind, it is necessary to have a point from which to start and a point to which to go. The same is also necessary in making a scale. One of the essential qualities of a thermometer is to enable observers in all parts of the world to indicate the same temperature by the same

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What is the use of the thermometer? What different kinds of thermometers have we? On what general principle do they all depend? What form of thermometer is the most common? What are the degrees? What temperature does it indicate if held in the hand? Why are fixed points necessary in forming the scale?

degree. A common system of dividing the scale must, therefore, be agreed upon, that all thermometers may correspond.

If we dip a thermometer in melting ice or snow, the quicksilver sinks to a certain point, and to this point it will always come, no matter when or where the experiment is made. If we dip it in boiling water, it at once rises to another point. Philosophers in all countries have agreed that these are the best fixed points to regulate the scale by, and accordingly they are now used in all thermometers. In the Fahrenheit thermometer, which is commonly employed in the United States, we mark the point at which the instrument stands, when dipped in melting snow, 32°, and that for boiling water, 212°, and divide the intervening space into 180 parts, each of which is a degree; and these degrees are carried up to the top and down to the bottom of the scale.

In other countries other divisions are used, adjusted, however, by the same fixed points. The Centigrade thermometer has, for the melting of ice, 0, and for the boiling of water, 100°, with the intervening space divided in 100 equal degrees. In Reaumur's thermometer, the lower point is marked 0, and the upper 80°.

The philosophical fact upon which the construction of the thermometer reposes, is that quicksilver expands by an increase of heat, and is contracted by a diminution of it; and further, that these expansions and contractions are in proportion to the changes of temperature.

Fig. 272.

But for particular purposes, thermometers have been made of oil, of alcohol, and of a great many other liquid bodies, and give rise to the same general results. As an uniform law it may, therefore, be asserted that all liquids dilate as their temperature rises, and contract as it descends.

But heat determines the volume of gases as well as of liquids. If we take a tube, *a*, *Fig.* 272, with a bulb at its upper extremity, *b*, and having partly filled the tube with a column of water, colored, to make its movements visible, the lower end dipping

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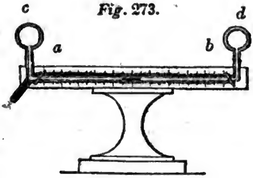
What two fixed points have been selected? What is the Centigrade scale? What is Reaumur's scale? What is the fact on which the construction of the thermometer depends? How may this be extended to other liquids?

loosely into some of the same colored water, contained in a bottle, *c;* on touching the bulb, *b*, the colored liquid in the tube is pressed down by the dilatation of the air, and on cooling the bulb the liquid rises, because the air contracts. And were the bulb filled with any other gaseous substance, such as oxygen, hydrogen, &c., still the same thing would take place. So gases, like liquids, expand as their temperature rises, and contract as it descends.

Such an instrument as *Fig.* 272, passes under the name of an air thermometer. Its indications are not altogether reliable, as may be proved by putting it under an air-pump receiver, when its column of liquid will instantly move as soon as the least change is made in the pressure of the air. It is affected, therefore, by changes of pressure as well as changes of temperature.

Fig. 273.



There is, however, a form of air thermometer which is free from this difficulty. It is the differential thermometer. This instrument consists of a tube, *a b*, *Fig.* 273, bent at right angles toward its ends, which terminate in two bulbs, *c d*. In the horizontal part of the tube is a little column of liquid marked by the black line, which serves as an index. If the bulb *c*, is touched by the hand, its air dilates and presses the index column over the scale; if *d* is touched the same thing takes place, but the column moves the opposite way; if both bulbs are touched at once, then the column, pressed equally in opposite directions, does not move at all. Of course, a similar reasoning applies to the cooling of the bulbs. The instrument is, therefore, called a differential thermometer, because it indicates the difference of temperature between its bulbs, but not absolute temperatures to which it is exposed.

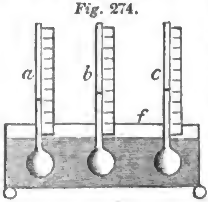
In the same manner that we have thermometers, in which the changes of volume of liquids and gases are employed, to indicate changes of temperature, so, too, we have others in which solids are used. These generally consist of a strip of metal which is connected with an ar-

How may it be extended to all the gases? Describe the air thermometer. Describe the differential thermometer. What does this instrument indicate?

rangement of levers or wheels, by which any variations in its length may be multiplied. The disturbing agencies, thus introduced by this necessary mechanism, interfere very much with the exactness of these instruments. And hitherto they have not been employed, except for special purposes, and can never supplant the mercurial thermometer.

It being thus established that all substances, gases, liquids, and solids expand as their temperature rises, and contract as it falls, it may next be remarked that great differences are detected when different bodies of the same form are compared. There are scarcely two solid substances which, for the same elevation of temperature, expand alike. All do expand; but some more and some less. In the case of crystalline bodies, even the same substance expands differently in different directions. Thus, a crystal of Iceland spar dilates less in the direction of its longer than it does in the direction of its shorter axis. The same holds good for liquids. If a number of thermometers, *a b c*, *Fig.* 274, of the same size be filled with different liquids, and all plunged in the same vessel of hot water, *f*, so as to be warmed alike, the expansion they exhibit will be very different. Until recently, it was believed that all gases expand alike for the same changes of temperature, but it is now known that minute differences exist among them in this respect. For every degree of Fahrenheit's thermometer atmospheric air expands $\frac{1}{493}$ of its volume at 32°.

Fig. 274.



Gases, liquids, and solids compared together, for the same change of temperature, exhibit very different changes of volume; gases being the most dilatable, liquids next, and solids least of all. This, probably, arises from the fact that the cohesive force, which is the antagonist of heat, is most efficient in solids, less so in liquids, and still less in gases.

Are thermometers ever made of solid bodies? What difficulties are in the way of their use? Do bodies of the same form expand alike? What remarks may be made respecting Iceland spar? How may it be proved that different liquids expand differently? What is the expansion of air for each degree? Do other gases expand exactly like air? Of gases, liquids, and solids, which expands most?

LECTURE L.

OF RADIANT HEAT.—*Path of Radiant Heat.—Velocity of Radiant Heat.—Effects of Surface.—Law of Reflexion.—Reflexion by Spherical Mirrors.—Theory of Exchanges of Heat.—Diathermanous and Athermanous Bodies.—Properties of Rock Salt.—Imaginary Coloration.*

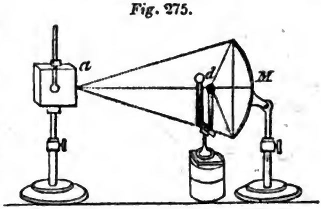
EXPERIENCE shows that whenever a hot body is freely exposed its temperature descends, until eventually it comes down to that of the surrounding bodies. There are two causes which tend to produce this result. They are radiation and conduction.

All bodies, whatever their temperature may be, radiate heat from their surfaces. It passes forth in straight lines, and may be reflected, refracted, and polarized like light.

The rate at which radiant heat moves is, in all probability, the same as the rate for light. It has been asserted that its velocity is only four fifths that of light, but this seems not to rest upon any certain foundation.

As respects the rapidity or facility with which radiation takes place, much depends on the nature of the surface. The experiments of Leslie show that, at equal temperatures, such as are smooth are far less effective than such as are rough. This result he established by taking a cubical metallic vessel, *a*, filled with hot water, the four vertical sides being in different physical conditions—one being polished, a second slightly roughened, a third still more so, and the fourth roughened and blackened. Under these circumstances, the rays of heat es-

Fig. 275.

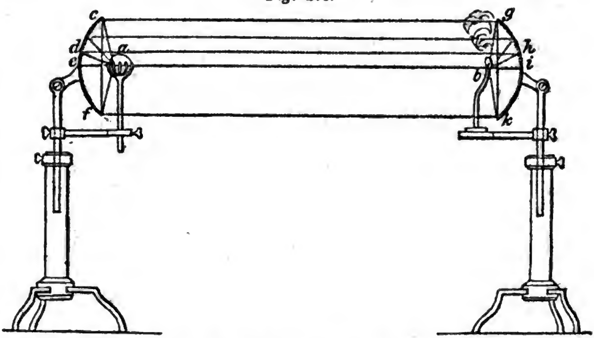


What causes tend to produce the cooling of bodies? In what direction does radiant heat pass? What is the velocity of its movement? How is the rapidity of radiation controlled by surface? Of smooth and rough bodies which are the best radiators?

caping from each surface as it was turned in succession toward a metallic reflector, M, raised a thermometer, *d*, placed in the focus, to very different degrees, the polished one producing the least effect.

Just as light is reflected, so, too, is heat. If we take a plate of bright tin and hold it in such a position as to reflect the light of a clear fire into the face, as soon as we see the light we also feel the impression of the heat. The law for the one is also the law for the other, "the angle of reflexion is equal to the angle of incidence," and consequently mirrors with curved surfaces act precisely in one case as they do in the other. We have already shown, Lecture XXXVII, how rays diverging from the focus of a mirror are reflected parallel, and how parallel rays falling on a mirror are converged. And it is upon that principle that we account for the following striking experiment. In the focus of a concave metallic mirror

Fig. 276.



let there be placed a red hot ball, *a*, *Fig.* 276, the rays of heat diverging from it in right lines, *a c*, *a d*, *a e*, *a f* will be reflected parallel in the lines *c g*, *d h*, *e i*, *f k*, and, striking upon the opposite mirror, will all converge to *b*, in its focus. If, therefore, at this point any small combustible body, as a piece of phosphorus, be placed, it will instantly take fire, though a distance of twenty or fifty feet may intervene between the mirrors. Or, if the bulb of an air thermometer be used instead of the phosphorus,

What is the law for the reflexion of heat? How do curved mirrors act on radiant heat? Describe the experiment represented by *Fig.* 276.

it will give at once the indication of a rapid elevation of temperature.

But this is not all; for, if still retaining the thermometer in its place, we remove away the red hot ball and replace it by a mass of ice, the thermometer instantly indicates a descent of temperature, the production of cold. At one time it was supposed that this was due to cold rays which escaped from the ice, after the same manner as rays of heat, but it is now admitted that the effect arises from the circumstance that the thermometer bulb, being warmer than the ice, radiates its heat to the ice, the temperature of which ascends precisely in the same manner as that in the former experiment, the red hot ball being the warmer body, radiated its heat to the thermometer.

In fact, these experiments are nothing more than illustrations of a theory which passes under the name of "the Theory of the Exchanges of Heat." This assumes that all bodies are at all times radiating heat to one another; but the speed with which they do this depends upon their temperature, a hot body giving out heat much faster than one the temperature of which is lower. If thus, we have a red hot ball and a thermometer bulb in presence of one another, the ball, by reason of its high temperature, will give more heat to the bulb than it receives in return; its temperature will, therefore, descend, while that of the bulb rises. But if the same bulb be placed in presence of a mass of ice, the ice will receive more heat than it gives, because it is the colder body of the two, and the temperature of the thermometer therefore declines.

All bodies are at all times radiating heat, their power of radiation depending on their temperature, increasing as it increases, and diminishing as it diminishes.

As is the case with light, so, too, with heat: there are substances which transmit its rays with readiness, and others which are opaque. We therefore speak of diathermanous bodies which are analogous to the transparent, and athermanous which are like the opaque.

What ensues if a piece of ice is used instead of a hot ball? How was this formerly explained? What is the true explanation of it? What is meant by the Theory of the Exchanges of Heat? On what does the rate of radiation depend? What are diathermanous bodies? What are athermanous ones?

Among the former a vacuum and most gaseous bodies may be numbered; but it is remarkable that substances which are perfectly transparent to light are not necessarily so to heat. Glass, which transmits with but little loss much of the light which falls on it, obstructs much of the heat; and, conversely, smoky quartz and brown mica which are almost opaque to light transmit heat readily. But of all solid substances, that which is most transparent to heat, or most diathermanous, is rock-salt; it has therefore been designated as the glass of radiant heat. If a prism be cut from this substance, and a beam of radiant heat allowed to fall upon it, it undergoes refraction and dispersion precisely as we have already described as occurring under similar circumstances with a glass prism for light in Lecture XL. And if convex lenses be made of rock-salt they converge the rays of heat to foci, at which the elevation of temperature may be detected by the thermometer. Heat, therefore, can be refracted and dispersed as easily as it can be reflected.

If we take a convex lens of glass and one of rock-salt, and cause them to form the image of a burning candle in their foci, it will be found on examination that the image through the rock-salt is hot, but that through the glass can scarcely affect a delicate thermometer. This experiment sets in a clear light the difference in the relations between glass and salt, the former permitting the light to pass but not the heat, the latter transmitting both together.

When light is dispersed by a prism the splendid phenomenon of the spectrum is seen. But in the case of heat our organs of sight are constituted so that we cannot discover its presence, and therefore fail to see the corresponding result. But it is now established beyond all doubt, that in the same manner that there are modifications of light giving rise to the various colored rays, so, too, there are corresponding qualities of radiant heat. Moreover, it has been fully proved that, as stained glass and colored solutions exert an effect on white light, absorbing some rays and letting others pass, the same takes place also for heat. In the case we have already con-

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Mention some of the former. Of all solid bodies which is the most diathermanous? What is to be observed when rock-salt and glass are compared?

sidered of the imperfect diathermancy of glass—the true cause of the phenomenon is the coloration which the glass possesses as respects the rays of heat, and inasmuch as a substance may be perfectly transparent to one of these agents and not so to the other, so, also, a body may stop or absorb a given ray for the one and a totally different one for the other. Glass allows all the rays of light to pass almost equally well, but it obstructs almost completely the blue rays of heat. The coloration of bodies, which has already been described as arising from absorption, may, therefore, be wholly different in the two cases; and as our organs do not permit us to see what it is in the case of heat, and we have to rely on indirect evidence, we speak of the imaginary or ideal coloration of bodies.

If heat like light, as there are reasons for believing, arises in vibratory movements which are propagated through the ether, all the various phenomena here described can be readily accounted for. The undulations of heat must be reflected, refracted, inflected, undergo interference, polarization, &c., as do the undulations of light, the mechanism being the same in both cases.

LECTURE LI.

CONDUCTION AND EXPANSION.—*Good and Bad Conductors of Heat.—Differences among the Metals.—Conduction and Circulation in Liquids.—Point of Application of Heat.—Case of Gases.—Expansion of Gases, Liquids, and Solids.—Irregularity of Expansion in Liquids and Solids.—Regularity of Gases.—Point of Maximum Density of Water.*

WHEN one end of a metallic bar is placed in the fire, after a certain time the other has its temperature elevated, and the heat is said to be conducted. It finds its

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What reasons are there for supposing that radiant heat is colored? Do natural bodies possess a peculiar coloration for heat? What is meant by ideal or imaginary coloration? If heat consists of ethereal undulations to what effects must it be liable? What is meant by the conduction of heat?

way from particle to particle, from those that are hot to those that are cold.

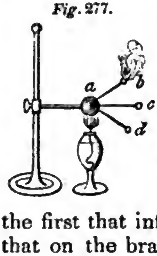
But if a piece of wood or of earthenware be submitted to the same trial a very different result is obtained. The farther end never becomes hot, proving, therefore, that some bodies are good and others bad conductors of heat.

The rapidity with which this conduction from particle to particle takes place, depends, among other things, upon their difference of temperature. Thus, when the bulb of a thermometer is plunged in a cup of hot water, for the first few moments its column runs up with rapidity, but as the thermometer comes nearer to the temperature of the water, the heat is transmitted to it more slowly.

Of the three classes of bodies solids are the best conductors, liquids next, and gases worst of all. Of solids the metals are the best, and among the metals may be mentioned gold, silver, copper. Among bad solid conductors we have charcoal, ashes, fibrous bodies, as cotton, silk, wool, &c.

That the metals differ very much in this respect from one another may be satisfactorily proved by taking a rod of copper, one of brass, and one of iron, *b c d*, *Fig.* 277, of equal length and diameter, and screwing them into a solid metallic ball, *a*, having placed on their farther extremities at *b c d*, pieces of phosphorus, a very combustible body. Now, if a lamp be placed under the ball, it will be found that the heat traverses the metallic bars with very different degrees of facility, and the phosphorus takes fire in very different times; the first that inflames is that on the copper, then follows that on the brass, and a long time after that on the iron.

Fig. 277.



Liquids are, for the most part, very indifferent conductors of heat. This may be established, for example, in the case of water, by taking a glass jar, *a*, *Fig.* 278, nearly filled with that substance, and introducing into it the bulb of a delicate air-thermometer, *c*, so that a very short space

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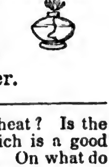
How may it be proved that different bodies conduct heat with different degrees of facility? How is this affected by difference of temperature? Of the three classes of bodies which conduct heat best? How may difference of conduction among metals be proved?

Fig. 278

intervenes between the top of the bulb and the surface of the liquid. If now some sulphuric ether be placed on that surface, and set on fire, it will be found that the thermometer remains motionless, and we therefore infer that the thin stratum intervening between the burning ether and the thermometer cuts off the passage of the heat. More delicate experiments have, however, proved that the liquid condition is not, in itself, a necessary obstruction. Even water does conduct to a certain extent; and quicksilver, which is equally a liquid, conducts very well.

But experience assures us that, under common circumstances, heat is uniformly disseminated through liquids with rapidity. This, however, is due to the establishment of currents in their mass. We have seen how readily this class of bodies expands under an elevation of temperature, and this explains the nature of the passage of heat through them. When the source of heat is applied at the bottom of a vessel containing water, those particles which are in immediate contact with the bottom become warmed by the direct action of the fire, and they therefore expand. This expansion makes them lighter, and they rise through the stratum above, establishing a current up to the surface. Meantime their place is occupied by colder particles, which descend, and these in their turn becoming warm follow the course of the former. Circulation, therefore, takes place throughout the liquid mass, in consequence of the establishment of these currents; and all parts being successively brought in contact with the hot surface, all are equally heated. That these movements do take place, may be proved by putting into a flask of water, *a*, *Fig.* 279, a number of fragments of amber, adding a little glauber salt to make their specific gravity of the liquid more nearly that of the amber, and then applying a lamp, currents are soon set up, and the amber, drifting in them, marks out their course in an instructive manner.

Fig. 279.

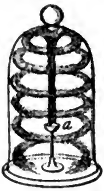


How may it be proved that liquids are bad conductors of heat? Is the liquid state a necessary obstruction? Mention a liquid which is a good conductor. How is heat then transmitted through liquids? On what do these currents depend? How may they be illustrated by means of amber?

Such currents, however, wholly depend on the point of application of the heat. If the fire, instead of being applied at the bottom of the vessel, is applied at the top, as in *Fig.* 278, then the liquid can never be warmed. The cause of the movements of particles is their becoming lighter—they therefore float upward; but if they are already situated on the surface of course no movement can take place.

With respect to gases we observe the same peculiarities that we do with liquids. Strictly speaking, they are very bad conductors of heat; but from the mobility of their parts, it is very easy to transfer heat readily through them, provided it is rightly applied. The experiment represented in *Fig.* 280, shows how easily circulation takes place in them. If a piece of burning sulphur be put in a cup, *a*, and a jar full of oxygen be inverted over it, the combustion goes on with rapidity, and the light smoke that rises marks out very well the path of the moving air. It rises directly upward from the burning mass, until it reaches the top of the jar, and then descends in circular wreaths to the bottom.

Fig. 280.



On the principle of the difference of the conductibility of bodies, we direct all our operations for the communication of heat with different degrees of rapidity. When we desire to abstract the heat rapidly from bodies, we surround them with good conductors; if we wish to retard it, we select such as are bad. And, indeed, it is in this way that we regulate our changes of clothing. Thick woollen articles, which are very bad conductors, are adapted to the cold winter weather, when we desire to cut off the escape of heat from our bodies as much as is in our power. Nature also resorts to the same principles—the thick coat of wool or of hair which serves for the covering of animals protects them from the cold by its non-conducting power. In these instances, in reality, the action of atmospheric air is brought into play, and that under the

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Why do such currents depend on the point of application of the heat? Do the same laws hold in the case of gases? How may this be proved by experiment? What applications are made of the principle of different conductibility? In the fur of animals how is the non-conducting power of air called into use?

most favorable circumstances; for any motion of its particles among the thickly matted fibres is impossible, and its non-conducting power, undisturbed by circulation, is rendered available.

It has been stated that all bodies expand under the influence of heat—gases being the most expansible, liquids next, and solids least. But the expansion of the two latter classes of bodies is far from being proportional to their temperature; for solids and liquids expand increasingly as their temperature rises—one degree of heat, if applied at 400°, produces a greater dilatation than if applied at 100°. From this irregularity it is believed that gases are free—they seem to expand uniformly at all temperatures.

Besides this general irregularity which applies to all solids and liquids, there are other special irregularities, often of great interest. Water may afford an example. If some of this liquid be taken at 32° and warmed, instead of expanding it contracts, and continues to do so until it has reached about 39½°, after which it expands. It therefore follows, that *if we take water at 39½°, whether we warm it or cool it, it expands.* At that temperature it is, therefore, in the smallest space into which it can be brought by cooling—it has, therefore, the greatest density, and 39½° is spoken of *as the point of maximum density of water.* In the same manner several other liquids, and even solids, have points of maximum density.

This fact is of considerable interest, when taken in connection with the circulatory movements we have been describing. When a mass of water cools on a winter's night, the colder particles do not contract and descend to the bottom, but after 39½° is reached, they, being the lighter, float on the top, and hence freezing begins at the surface. Were it otherwise, and the liquid solidified from the bottom upward, all masses of water during the winter would be converted into solid blocks of ice, instead of being merely covered as they are with a screen of that substance, which protects them from further action.

Do solids and liquids expand with regularity? Are there other irregularities besides this? What is meant by the maximum density of water? At what temperature does it take place? How does this effect the freezing of masses of water?

LECTURE LII.

CAPACITY FOR HEAT AND LATENT HEAT.—*Illustration of the Different Capacities of Bodies for Heat.—Standards employed.—Process by Melting.—Process of Mixtures.—Effects of Compression.—Effect of Dilatation.—Latent Heat.—Caloric of Fluidity.—Caloric of Elasticity.—Artificial Cold.*

BY the phrase capacity of bodies for heat we allude to the fact that *different bodies require different degrees of heat to warm them equally.*

An experiment will serve to illustrate this important fact. If we take two bottles as precisely alike as we can obtain them, and, having filled one with water and the other with quicksilver, set them before the same fire, so as to receive equal quantities of heat in equal times, it will be found that the water requires a very much longer exposure, and therefore a larger quantity of heat than the quicksilver to raise its temperature up to the same point.

Or if we do the converse of this, and take the two bottles filled with their respective liquids, which, by having been immersed in a pan of boiling water, have both been brought to the same degree, and let them cool freely in the air, it will be found that the water requires much more time than the quicksilver to come down to the common temperatures. It contained more heat at the high temperature than did the quicksilver, and required more time to cool; it has, therefore, a greater capacity for heat; or, to use a loose expression, at the same temperature holds more of it.

There are several different ways by which the capacity of bodies for heat may be determined. Thus, we may notice the times they require for warming, or those expended in cooling in a vacuum. Of course, we cannot

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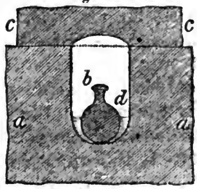
What is meant by the capacity of bodies for heat? Illustrate this by experiment. Can it be proved conversely? In what ways may the capacity of bodies be determined? Can the absolute amount of heat in bodies be determined?

tell the absolute amount of heat which is contained in any substance whatever, and these determinations are hence relative—different bodies being compared with a given one which is taken as a standard. For these purposes water is the substance selected for solids and liquids and atmospheric air for gases and vapors.

An illustration will show the methods by which the capacity of bodies is determined by the process of melting. Let there be provided a mass of ice, *a a*, *Fig.* 281, in which a cavity, *b d*, has been previously made, and a slab of ice, *c c*, so as to cover the cavity completely. In a small flask, *d*, place an ounce of water, raised to a temperature of 200°. Set this in the cavity, as shown in the figure, and put on the slab. The ice now begins to melt; and, as the water forms, it collects in the bottom of the cavity. When the temperature of the flask has reached 32° it only remains to pour out the water and measure it. Next, let there be put in the flask an ounce of quicksilver, the temperature of which is raised, as before, to 200°; measure the water which it can give rise to by melting the ice, precisely as in the former experiment, and it will be found that the water melted twenty-three times as much as the quicksilver. Under these circumstances, therefore, a given weight of water gives twenty-three times as much heat as the same quantity of quicksilver.

Fig. 281.



There are still other means of obtaining the same results. Such, for instance, as by the method of mixtures. If a pint of water at 50° be mixed with a pint at 100° the temperature of the mixture is 75°; but if a pint of mercury, at 100°, is mixed with a pint of water, at 40°, the temperature of the mixture will be 60°, so that the 40° lost by mercury only raised the water 20°. That this result may correspond with the foregoing, it should be recollected that, in this instance, we are using equal *volumes*, in that equal *weights*.

Why is capacity a relative thing? What is the standard for solids and liquids? What is it for gases and vapors? Describe the process for determining capacities by melting. How do water and quicksilver compare? Describe the process by mixtures. In this, how do water and quicksilver compare?

In this way the capacities of a great number of bodies have been determined, and tables constructed in which they are recorded. Such tables are given in the books of chemistry. The different capacities of bodies are also designated by the term specific heat, since it requires a *specific* quantity of heat to heat bodies equally.

When a body is compressed, its specific heat or capacity for heat diminishes, and a portion makes it appearance as sensible heat. This may be proved by rapidly compressing air, which will give out enough heat to set tinder on fire, or by beating a piece of iron vigorously, when it may be made red hot. On the other hand, when a body is dilated its capacity for heat increases. It is partly for this reason that the upper regions of the atmosphere are so cold the specific heat is great by reason of the rarity. It therefore requires a large amount of heat to bring the temperature up to a given point.

It has also been found that the specific heat changes with the temperature, increasing therewith, so that it is not constant for the same body.

There is reason to believe that the atoms of all simple substances have an equal capacity for heat; and that all compound bodies, composed of an equal number of single atoms combined in one and the same manner, have a capacity for heat which is inversely as their specific gravity.

When a solid substance passes into the liquid form a large quantity of heat is rendered latent—that is to say, undiscoverable to the thermometer. Thus, we may have ice at 32° and water at 32°, the one a solid and the other a liquid, and the precise reason of the physical difference between them is, that the water contains about 140°, which the ice does not—a quantity which is occupied in giving it the liquid state, and is insensible to the thermometer.

For this reason the transformation of a solid into a liquid is not an instantaneous phenomenon, but one requir-

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What is meant by specific heat? How does specific heat change under compression? Does this take place in solids as well as gases? What reason is there for the cold in the upper regions of the air? Does specific heat vary with the temperature? What is observed respecting the atoms of simple bodies? What respecting compound? What is latent heat? What is the latent heat of water? Why does the transformation of water into ice or ice into water require time?

ing time. Ice must have its 140° degrees of latent heat before it can turn into water. And, conversely, the solidification of a liquid is not instantaneous. It must have time to give out the latent heat to which its liquid state is due.

When a liquid passes into the form of a vapor it is the presence of a large quantity of latent heat which gives to it all its peculiarities. Thus, water in turning into steam absorbs nearly 1000° of latent heat, and when that steam reverts into the liquid state the heat reappears.

To the caloric which is absorbed during fusion, the designation of *caloric of fluidity* is given, to that which gives their constitution to vapors the name of *caloric of elasticity*. And as different bodies require during these changes different quantities of heat, there are furnished in the works on chemistry tables of the caloric of fluidity, and caloric of elasticity of all the more common or important bodies. Of all known bodies water has the greatest capacity for heat; and, in consequence of the great amount of latent heat it contains, it is one of the great reservoirs of caloric, both for natural and artificial purposes.

Hence, whenever a substance melts it absorbs heat, and when it solidifies it gives out heat. When a substance vaporizes it absorbs heat, and when a vapor liquefies it evolves heat.

On these principles depend some of the processes resorted to for the production of cold. If we take two solid bodies, as salt and snow, which have such chemical relations to one another that, when mixed, they produce a forced fusion and enter on the liquid state; before that change of form can take place, caloric of fluidity must be supplied, for snow cannot turn into water unless heat is given it. The mixture, therefore, abstracting heat from any bodies around or in contact with it, brings down their temperature and thus produces cold. The same result attends the vaporization of a liquid; thus, ether poured on the hand or on the thermometer produces a great

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What is the physical difference between water and steam? What is the caloric of fluidity? What is the caloric of elasticity? What substance has the greatest capacity for heat? Why is cold produced by a mixture of salt and snow? Why is it produced by the vaporization of ether?

cold, because the vapor which rises must have caloric of elasticity in order to assume its peculiar form, and it takes heat from the body from which it is evaporating for that purpose.

LECTURE LIII.

On Evaporation and Boiling.—*Phenomena of Boiling.—Effect of the Nature of the Vessel and the Pressure.—Height of Mountains Determined.—Effect of Increased Pressure.—Evaporation.—Vaporization in Vacuo.—Effect of Temperature on a Liquid in Vacuo.—Explanation of Boiling.—Nature of Vapors.*

As the vaporization of liquids is connected with some of the most important mechanical applications, we shall proceed to consider it more minutely.

When water is placed in an open vessel on the fire the temperature of the whole mass ascends on account of the currents described in Lecture LI. After a time minute bubbles make their appearance on the sides of the vessel; these rise a little distance and then disappear, but others soon take their places, and the water, being thrown into a rapid vibratory motion, emits a singing sound. Immediately after this the little bubbles make their way to the surface of the liquid, and are followed by others which are larger, and the phenomenon of boiling takes place. The heat has now reached 212°, and it matters not how hot the fire may be, it never rises higher.

Different liquids have different boiling points, but for the same body, under similar circumstances, the point is nearly fixed. It is, indeed, in consequence of this that the boiling of water is taken as the upper fixed point of the thermometer.

Of the circumstances which can control the boiling point, two may be mentioned: the nature of the vessel and the pressure of the air.

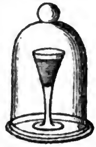
In a polished vessel, for instance, water does not boil

Describe the different phenomena exhibited during the warming of water. At what temperature does ebullition set in? What circumstances control the boiling point? In a polished vessel what is the temperature?

until 214°; but if a few grains of sand or other angular body is thrown in the temperature sinks to 212°.

The absolute control which pressure exerts over the boiling point may be shown in many different striking ways. Thus, if a glass of warm water be put under the receiver of an air-pump and exhaustion made, the water enters into rapid ebullition, and continues boiling until its temperature goes down to 67°. Water placed in a vacuum will therefore boil with the warmth of the hand.

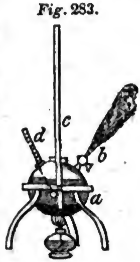
Fig. 282.



Advantage has been taken of this fact to determine the height of accessible eminences. For, as we ascend in the air, the pressure necessarily becomes less; the superincumbent column of the atmosphere being shortened, the boiling point therefore declines. It has been ascertained that if we ascend from the ground through 530 feet, the boiling point is lowered one degree; and formulas are given by which, from a knowledge of that point, in any instance the altitude may be calculated.

On the other hand, when the pressure on a liquid is increased, its boiling point ascends. This may be proved by taking a spherical boiler, *a*, properly supported over a spirit lamp, there being in its top three openings; through *d* let a thermometer dip into some water which half fills the boiler, at *b* let there be a stop-cock which can be opened and shut at pleasure, and through a third opening between these let a tube, *c*, pass, dipping down nearly to the bottom of the boiler into some quicksilver which is beneath the water. Now let the water boil freely and the steam escape through *b*, the thermometer will mark 212°. Close the stop-cock so that the steam cannot get out, but, being confined in the boiler, exerts a pressure on the surface of the water, which is indicated by the rise of the mercury in the tube. As the column rises the boiling point rises, and if the instrument were

Fig. 283.



Prove that it is affected by pressure. At what temperature will water boil in an air-pump vacuum? How has this been applied for the determination of heights? How does the boiling point vary when the pressure is increased?

adapted to show the results for high pressures, it might be proved that the boiling point

For 1 atmosphere is		212°	For 10 atmospheres is		358.8
2	"	250.5	15	"	392.8
3	"	275.2	20	"	418.5
4	"	293.7	40	"	666 5
5	"	307.5	50	"	690.7

Besides this escape of vapor from liquids during the act of boiling, the same is continually going on in a slow and motionless way, at lower temperatures. If some water be left in a shallow vessel exposed to the air, after a short time it all disappears. To this phenomenon the term evaporation is given.

At one time it was supposed that the atmospheric air acted on evaporating bodies by an affinity for their vapors, in the same way that a sponge will soak up water. But the fallacy of this idea is proved by the fact that evaporation goes on more rapidly in vacuo, where no body whatever is present, than in the air. Thus, if into the torricellian vacuum of a barometer, we pass a little ether, alcohol, or water, the moment they reach the void they instantly give forth vapor, and the mercurial column is depressed. With ether the depression is greatest, with alcohol less, and with water least of all. Now when we consider the nature of the barometer, and the force which keeps the column of mercury suspended in it, it is very clear that this simple method affords us an easy means of knowing the elastic force of the vapors evolved from any of these substances: for the mercurial column is depressed through the operation of that elastic force. It is this which forces it downward, while the pressure of the air tends to force it upward.

Fig. 284.

By thus introducing liquids into the barometric tube, we have the means of determining the elastic force of the vapors to which they give rise; and very simple experiments satisfy us that that elastic force depends upon the the temperature. If we warm the tube, *Fig.* 284, by-

Give some examples of the boiling point for different pressures. What is meant by evaporation? How can it be proved that the air does not act by its porosity like a sponge? What takes place when a liquid is passed into a torricellian vacuum? How can we measure the elastic force of the vapor evolved?

moving over it the flame of a spirit-lamp, the depression becomes greater, and if we surround it by means of warm water in a wider tube, so as to be able to ascertain with accuracy the temperature applied, we shall discover that as the heat rises the elastic force of the vapor increases, and that *the mercurial column is wholly depressed into the cistern as soon as the temperature has reached the boiling point of the liquid on which we are operating.*

Thus, let A be a deep glass jar, filled to the height *n* with mercury, and let *a b* be the barometric tube, into the vacuum of which, at *m*, the liquid under trial has been passed. Let a wide tube, *r c*, capable of holding hot water, be adapted, by means of a tight-fitting cork, at *s*, to the barometric tube. Now if, having observed the depression which the mercury exhibits at common temperatures, we fill the tube, *r c*, with hot water, a still greater depression is the immediate result. The temperature of the hot water, and, therefore, of the liquid in the barometer, can easily be determined by plunging a thermometer into the tube, *r c*.

Fig. 285.

From such experiments, therefore, we draw this important conclusion: *The elastic force of vapor rising from a liquid at its boiling point is equal to the pressure upon it.* If the ebullition be taking place in the open air, it is therefore equal to the pressure of the air.

This principle furnishes a complete explanation of the process of boiling, previously described. As the temperature of a mass of liquid exposed to heat gradually rises, the elastic force of the vapor it generates increases. Very soon, therefore, on the hottest part of the vessel, that part in immediate contact with the fire, the temperature reaches such a point that the vapor can form, the elastic force of which is just equal to the atmospheric pressure. Little bubbles now rise; but these, having to pass up through a stratum above, which is of a temperature somewhat lower, are crushed in and disappear. They therefore throw

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Prove that that elastic force depends on the temperature. What is the elastic force when the boiling point is reached? What is the elastic force of a vapor when ebullition takes place in the air? How are these principles connected with the process of boiling? Why is a singing sound emitted?

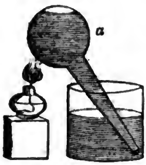
the liquid into a vibratory motion, and cause the singing sound. But soon the whole liquid attains such a degree of heat that the bubbles can make their way to the top, and then bursting, the phenomenon of ebullition fairly sets in.

With respect to the nature of vapors, there is a good deal of popular misconception. Many persons suppose that they are naturally of a smoky or hazy aspect. But if we repeat the experiment represented in *Fig.* 286, and formerly described in Lecture VI., we shall find that so far as the vapor of ether is concerned, it is perfectly transparent, like atmospheric air, and by proper examination the same may be verified for all other vapors. The true peculiarity is the facility with which this form of bodies assumes the liquid state. The moment the pressure of the air is restored, in this experiment, the ethereal vapor collapses into the liquid condition.

Fig. 286.

The same fact may be illustrated in another way. If we take a mattrass, *a*, *Fig.* 287, and fill the bulb and tube of it with water, and then introduce a little sulphuric ether into its upper part, the mouth dipping beneath some water contained in a jar, on heating the bulb by a spirit-lamp the ether presently vaporizes. It may now be remarked—1st. That a vapor occupies a great deal more space than the liquid from which it comes; 2d. That it has not a misty appearance, but is perfectly transparent; 3d. That, under a reduction of temperature, it collapses into the liquid state—for, on removing the lamp and suffering the bulb to cool, the vapor disappears.

Fig. 287.



Either by diminution of temperature or increase of pressure, vapors may be condensed into the liquid state, and in this consists the chief distinction between them and gases.

How can it be proved that vapors are not of a misty aspect? What is their true peculiarity? What does *Fig.* 287 illustrate? What three facts are proved by it? How may vapors be condensed into the liquid state?

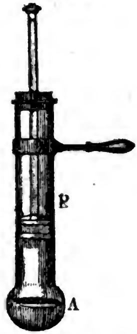
LECTURE LIV.

THE STEAM ENGINE.—*Elementary Steam Engine.—Forms of this Machine.—Description of the High-Pressure Engine.—Principle of the Low-Pressure Engine.—Description of the Double-Acting Engine.—Estimate of Performance.*

ON the elastic force of steam and on the rapidity with which it is condensed by application of cold, the construction of the different forms of steam engine depends.

The instrument represented in *Fig.* 288 gives a clear idea of the elementary parts of a steam engine. It consists of a cylindrical glass tube, B, terminating in a bulb, A. In the tube a piston moves up and down, air-tight, and a little water having been placed in the bulb, it is brought to the boiling point by the application of a lamp. As the steam forms it presses the piston upward by reason of its elastic force, and on dipping the bulb into cold water the steam condenses, and produces a partial vacuum, the piston being driven downward by the pressure of the air.

Fig. 288.



There are a great many modifications of the steam engine. They may, however, for the most part, be reduced to two kinds: 1st, high-pressure engines; 2d, low-pressure engines.

The high-pressure engine, which is the simplest of the two forms, consists essentially of a very strong iron vessel or boiler, in which the steam is generated, a cylinder, in which a steam-tight piston moves backward and forward, an arrangement of valves or cocks, so adjusted as alternately to admit the steam above and below the piston, and also alternately to let it escape into the air;

On what two principles do the different kinds of steam engine depend? Describe the instrument represented in *Fig.* 288. What are the chief varieties of the steam engine? Describe the high-pressure engine.

and lastly, a suitable contrivance by which the oscillations of the piston may be converted into other kinds of motion, suited to the work which the engine has to perform.

The action of the steam in one of these machines may be understood from the annexed diagram, *Fig.* 289. Let *f* be the cylinder, in which a solid piston, *e*, moves, steam-tight, and let us suppose the piston near to the bottom of the cylinder. The steam is now admitted through an aperture, *a*, and by its elastic force pushes the piston to the top of the cylinder. The movement of the piston-rod rearranges the openings into the cylinder, closing at a particular moment *a*, through which the steam has already come, and opening *b*; simultaneously, also, it opens *c* and closes *d*. Through *c*, from the boiler, a fresh supply of steam arrives, while it is shut off from *a*. This steam cannot escape through *d*, because that is closed—it therefore takes effect upon the piston and pushes it downward, all the vapor beneath escaping out into the air through *b*, which has been opened. This downward movement of the piston-rod rearranges all the valves, reversing the positions they have just had. It therefore opens *a*, shuts *b*, opens *d*, and shuts *c*. Steam now comes in from the boiler, through *a*, but cannot escape through *b*; it therefore pushes up the piston, driving out the steam, which is on its opposite side, through *d*, and in this way a reciprocating motion is produced.

Fig. 289.

The means of opening and shutting the apertures leading into the cylinder at the proper moment differ in different engines—sometimes cocks are used, and sometimes sliding valves.

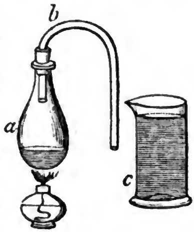
In this engine, therefore, the piston moves in both ways against the pressure of the air. The steam must be necessarily raised from water at a high boiling point, and hence these machines are much more liable to accident than the low-pressure engine, now to be described.

The rapid condensibility of steam—a principle inti-

Describe the circumstances under which the steam is alternately admitted above and below the piston. How are the necessary apertures opened and closed? Why must the steam be raised at high pressure?

mately concerned in the action of the low-pressure engine—may be illustrated in the following manner: Take a glass flask, *a*, *Fig*. 290, and adjust to its mouth a wide bent tube, *b*, both ends of which are open, having previously placed a quantity of water in the flask. Apply the flame of a spirit-lamp, and bring the water to the boiling point, continuing the ebullition until all the air is driven out of the flask, and nothing but steam remains. Then dip the open end of the tube into the jar, *c*, containing some cold water, and remove the lamp; the steam in the tube will at once begin to condense, through the influence of the cold water, which soon rises over the bent portion and precipitates itself into the flask, often with so much violence as to break it to pieces.

Fig. 290.



Of the low-pressure engine we have varieties—such as the single-acting and the double-acting engine. In the former, the piston is driven one way by means of steam acting against a vacuum, returning the other way by the counterpoising weight of the machinery. The machine, therefore, in reality, is only in action during half its motion.

The double-acting engine has the steam employed to produce both the ascent and descent of the piston into a vacuum on the opposite side. It therefore works continuously.

In expansive engines the supply of steam, instead of being continued during the entire ascent or descent of the piston, is cut off when the movement is one half or one third accomplished. The expansion of that steam driving the piston through the rest of the cylinder.

The following is a description of the double-acting engine: *Fig*. 291 represents the boiler and its appurtenances, *Fig*. 292 the engine.

B B, *Fig*. 291, is the boiler, of a cylindrical shape, the fire, F F, is applied beneath, W W is the water-level, and S is occupied by steam. At *t t* there is a bent glass

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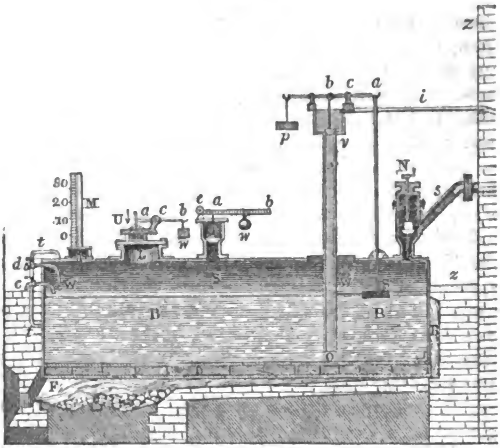
Give an illustration of the instantaneous condensation of steam. What is the nature of the single-acting steam engine? What is meant by the expansive engine? What is the double-acting engine?

tube, open at both extremities, and so arranged that one end is in the steam-space, and the other in the water;

Fig. 291.



it serves to show the level of the water in the boiler. In some cases, two cocks, *c* and *d*, are inserted in the boiler, one entering into the steam part and one beneath the water. On opening them, if the water is at its proper level, steam will escape from the upper and water from the under one. If there is too much water, it escapes from both; if two little, steam escapes from both. The boiler is continually replenished by the *feed-pipe*, the nature of which has been explained in Lecture XIV. At M there is a barometer-gauge, to show the elastic force of the steam; at *e a b* a safety-valve, with its weight, *w*; this opens upward, so that, should the elastic force in the interior of the boiler become too great, the valve opens, and the steam escapes. On the contrary, to prevent the boiler being crushed in by the atmospheric pressure, when the expansive force of the steam happens to decline, there is a second valve at U, with its lever, *a c b*,

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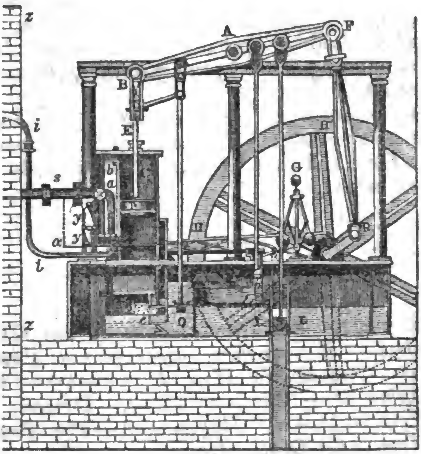
Describe the principal parts of its boiler. What are the two safety-valves?

and weight, *w*, which opens inward, that, when the external pressure exceeds the weight, the air may find access to the inside of the boiler. And, as it is necessary from time to time to clear the boiler from the incrustations or deposits of salt and other impurities, there is an opening, as at L, through which access can be had. This, of course, is, at other times, securely closed. Lastly, from the boiler there passes the steam-pipe, *s*, which is opened by the valve at N.

Fig. 292 represents the engine, properly speaking. At

Fig. 292.



z z it should be imagined as being continuous with *z z* of *Fig.* 291, so that in both figures the tubes *i i* and *s s* are continuous. In both *s* is the tube along which the steam from the boiler is delivered to the cylinder. Passing through the *four-way* cock, *a*, either down through *a* or up through *b*, into the cylinder C, in which the piston, P, moves. Admission for the steam, above or below the piston, is regulated by a system of levers, *y y*, the necessary motion being communicated by the machine itself.

Describe the principal parts of the engine. What becomes of the steam when it leaves the cylinder?

The piston-rod, E, is connected with the beam, B F, working on the fulcrum, A. The connecting-rod is F R. At R it is attached to the crank by a pivot, H H H, being the fly-wheel, the revolution of which gives uniformity to the motion. The steam, after elevating or depressing the piston, passes through the eduction-pipe, *f f*, into the condenser, J, which is immersed in a cistern, L, of cold water. In this it is condensed into water by a jet which passes through the injection-cock. The resulting warm water is pumped out by the air-pump, O, into the hot well, W; thence it is carried, by the hot-water pump, *b*, along the feed-pipe, *i i*, into the boiler. The cold-water pump, S, supplies the reservoir with cold water. All the pumps are worked by the beam of the engine. The supply of steam is regulated by the governor, G, so as to be kept constant.

The performance of steam engines is commonly estimated by horse-power. The value of the power of one horse is a force sufficient to raise 33,000 pounds one foot high in one minute.

LECTURE LV.

HYGROMETRY, OR THE MEASUREMENT OF THE QUANTITY OF VAPOR.—*Hygrometers.—Sponge and Paper Hygrometers.— Saussure's Hair Hygrometer.— Mode of Graduating it.— The Dew Point.— Process for the Dew Point.—Daniel's Hygrometer.—The Psychrometer.—Process for Drying Gas.*

FOR many scientific purposes it is often necessary to determine the amount of vapor of water in the air or in various gases. We have already observed, Lecture III, that the quantity of moisture in the atmosphere is constantly changing; and this is connected with a great number of interesting meteorological phenomena.

Instruments have been invented with a view of giving indications of the relative degrees of dampness of the air.

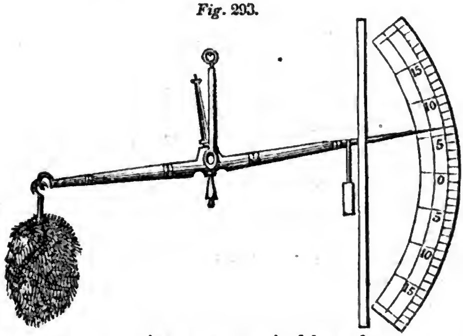
What is done with the resulting hot water? How are the movements of the different pumps and valves accomplished? What is the value of a horse-power?

They have received the names of hygroscopes and hygrometers.

A great many organic substances change their dimensions according as they are exposed to various degrees of moisture, expanding or contracting. Among such may be mentioned ivory, hair, whalebone, wood, &c. Any of these connected with a mechanism, by which the change of volume might be registered, would furnish a hygrometer. They all, however, lose their sensitiveness in the course of time. Thus, it is well known that wood, when it is seasoned, is much less liable to these changes than when it is in a recent state.

There are other bodies, among which might be enumerated many salts, which, by absorbing moisture from the air increase in weight, and by returning it back again, become lighter. Most of the powerful acids, as the sulphuric, also the alkalies, as potash and soda, possess an intense affinity for water. Advantage has been taken of this property in the construction of hygrometers, by attaching a sponge, soaked in weak pearlash, to one arm of a balance, the index of which plays over a graduated scale, and shows the influence of the existing moisture by the sponge becoming heavier or lighter. For such

Fig. 293.

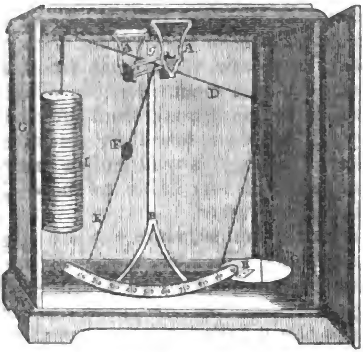


contrivances paper is a very suitable substance. Thus, let G G, *Fig* 293, be a case, the front of which is of glass and the sides of gauze or some other material, pervious to the air; let D be the beam of a light balance suspend-

What are hygroscopes or hygrometers? Mention some bodies which change under the influence of moisture. Describe the sponge hygrometer.

ed within, working on the fulcrum *g*, and supported by two brackets, A A. From the beam let there pass an index,

Fig. 294.



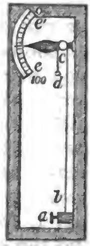
E, which moves over a scale, C, graduated into 100 equal parts, and suspended on a support, B. From one end of the beam let there hang the hygroscopic body, I, which consists of a great number of round pieces of thin paper, fastened together by three or more threads, forming a column, with spaces between each of the parallel pieces of paper, that the air may have complete access to the whole mass. This hygroscopic body is properly counpoised by a weight, H, in the opposite scale-pan. At F there is a button, which slides upon the index; it is to be arranged in such a position that a weight of one grain put on the top of the hygroscopic body will drive the index from 0 to 100 exactly. The papers are now to be thoroughly dried, by placing a dish of sulphuric acid in the case, or in any other suitable manner; and when that is accomplished, weights are to be added at H to bring the index to 0. When, now, it is exposed to the air, the papers become heavier, and the index plays over the scale. The instrument, therefore, acts from the dry extreme; but, though its movements are interesting, for it is constantly traversing, it is devoid of exactitude.

The hair hygrometer of Saussure is more simple and effectual. It consists of a human hair 8 or 10 inches

Describe the hygrometer reoresented in *Fig*. 293. From what extreme does this instrument act?

long, *b c*, *Fig.* 295, fastened at one extremity to a screw, *a*, and at the other passing over a pulley, *c*, being strained tight by a silk thread and weight, *d*. From the pulley there goes an index which plays over the graduated scale *e e′*, so that, as the pulley turns through the shortening or lengthening of the hair, the index moves. The instrument is graduated to correspond with others by first placing it under a bell jar along with a dish of sulphuric acid, caustic potash, chloride of calcium, or other substance having an intense affinity for water, this absorbs all the moisture of the air in the bell, and brings it to absolute dryness. The hair, therefore, contracts and moves the pulley and its index. When this contraction is complete, the point at which the index stands is marked 0. The hygrometer is then placed under a jar, the interior of which is thoroughly moistened with water and set in a vessel with that liquid, so as to bring the included air to a condition saturated with moisture. The index moves, and when it has become stationary the point opposite to which it stands is marked 100°. The intervening space is then divided into 100 equal parts, and the instrument is complete.

Fig. 295.



It is to be observed that the hair requires some previous preparation to give it its full hygrometric sensibility; this is accomplished by removing from it all oily matter by soaking it in a weak solution of potash.

As respects the nature of the indications of this instrument, it is to be understood, that it by no means follows that, when the index stands at 25 or 50, the air contains one quarter or one half the moisture it does at 100. Tables have, however, been constructed, which exhibit the value of its degrees.

A much more exact method is that known as *the process for the dew point.* In practice it is very simple, and may be thus described. If we take a glass of water, and, by putting in it pieces of ice, cool it down, after a time moisture will begin to dim the outside. If a thermometer

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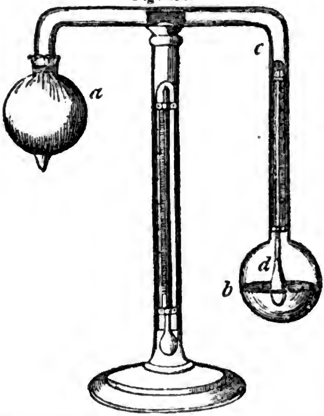
Describe the hair hygrometer of Saussure. How are its two fixed points of absolute dryness and maximum moisture found? What previous preparation does the hair require? What is to be observed as respects its indications?

is immersed in the water we may determine the precise degree at which this deposit takes place; and, knowing the temperature of the external air for the time being, we can tell the number of degrees through which it must be cooled before the dew point (or the point at which moisture deposits) is reached. Now, when the air is very moist it is necessary to cool it very little before this effect ensues; but when it is dry the cooling must be carried to a correspondingly lower degree. If the air were perfectly saturated the slightest depression of temperature would make the moisture precipitate. Knowing, therefore, the dew point, the barometric pressure, and the existing temperature, if it is required to find the actual quantity of moisture in the air it can be determined by calculation.

Daniel's hygrometer is a very beautiful instrument for determining the dew point. It consists of a bent tube, *a c b*, *Fig.* 296, at the extremities of which two bulbs, *a b*, are blown; *b* is made of black glass and *a* is covered over with a piece of muslin. The bulb *b* is half full of ether, and the instrument-maker contrives things so that the rest of the tube is void of air, and contains the vapor of ether only. A delicate thermometer, *d*, has its bulb dipping into the ether of *b*. There is also another thermometer attached to the stem of the instrument. Under these circumstances, if the muslin cover of *a* is moistened with a little ether, that bulb becomes at once cooled by the evaporation, the vapor within it condenses and a fresh quantity distils over from *b* to supply its place. But *b* cannot furnish the vapor without its own temperature descending, for latent heat

Fig. 296.

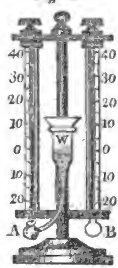


Describe the process for the dew point. What is Daniel's hygrometer? How is this instrument used?

is required before the vapor can form. After a time, therefore, through the cooling agency dew begins to deposit on the black glass, and the point at which this takes place is determined by the included thermometer.

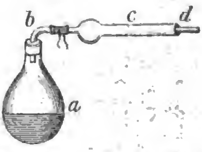
The *psychrometer* consists of two delicate mercurial thermometers divided into fractions of degrees, and corresponding perfectly with one another. The bulb of one of them, A, *Fig.* 297, is covered with muslin, that of the other, B, is left naked. On the central pillar there is arranged a reservoir, W, of distilled water, from which a thread passes to the muslin of A, and keeps it constantly moist, as the water evaporates from this bulb the mercury begins to fall, and the drier the air the greater the descent. As soon as the air round the bulb is saturated with moisture the point at which the mercury stands is the dew point. If both thermometers, the damp and the dry, coincide, the air contains moisture at its maximum density, and the greater the difference between them the dryer the air.

Fig. 297.



For many purposes in chemistry and physical science it is necessary to remove all moisture from atmospheric air and from gases. This may be done by conducting them through tubes containing bodies which have a strong attraction for water. The bodies commonly selected for this purpose are chloride of calcium, hydrate of potash, phosphoric acid, and fragments of glass or quartz moistened with oil of vitriol. The process is as represented in *Fig.* 298, where *a* is the flask from which the gas to be dried is evolved, *b* a bent tube which conducts it into a wider tube, *c*, containing the absorbent material. It escapes from *d* in a dry state.

Fig. 298.



Describe the psychrometer. Why does one thermometer commonly stand lower than the other? What substances are used in chemistry as drying agents? How are they employed?

MAGNETISM.

LECTURE LVI.

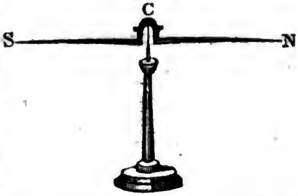
Magnetism.—*The Loadstone.—Artificial Magnets.—Polarity.—Transmission of Effect.—The Poles and Axis.—Magnetic Curves.—Law of Attraction and Repulsion.—Transient Magnetism of Iron.—Permanent Magnetism of Steel.—Induced Magnetism.—Law of Diminution.—Simultaneous Existence of Polarities.—Processes for Imparting Magnetism.*

Many centuries ago it was discovered that a certain ore of iron, which now passes under the name of the magnet or loadstone, possesses the remarkable quality of attracting pieces of iron. Subsequently it was found that the same power could be communicated to bars of steel, by methods to be described hereafter.

Fig. 299.

Bars of steel so prepared pass under the name of artificial magnets, to distinguish them from the natural loadstone. When they are of small size they are commonly called needles. A magnetic bar bent into the shape represented in *Fig.* 299, is called a horse-shoe magnet, and several magnets applied together take the name of compound magnets, or a bundle of magnets.

Fig. 300.



The Chinese discovered that when a magnetic needle is poised on a pivot, as in

What is the magnet or loadstone? What are artificial magnets? What are needles? What is a horse-shoe magnet?

Fig. 300, or floated on water by a piece of cork, that it spontaneously takes a direction north and south; and if purposely disturbed from that position it returns to it again after a few oscillations.

By a needle so suspended, the fundamental fact of the attraction of the magnet for iron is easily verified. Present a mass of iron to either extremity of the needle, and the needle instantly moves to meet it.

If a bar magnet is brought near a nail or a mass of iron-filings, the iron will be suspended.

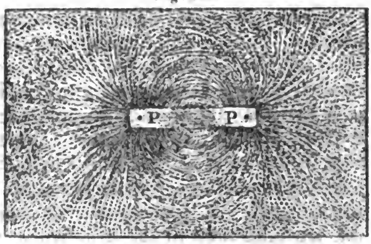
That these effects take place through glass, paper, and solid and liquid substances generally, may be thus established. A quantity of iron-filings being laid on a pane of glass, if a magnet be approached beneath, the filings follow its motions. But if a plate of *iron* intervenes the magnetic influence is almost wholly cut off.

The power of a magnetic bar is not equal in all parts. There is a point situated near each end, which seems to be the focus of action. To these points the names of *poles* are given, and the line joining them is called the axis.

Fig. 301

If a bar magnet be rolled in iron-filings, they attach themselves for the most part at the two poles, *d d*, *Fig.* 301: or, if such a bar be placed under a sheet of pasteboard, on the surface of which filings are dusted, they arrange themselves in curved lines, as shown in *Fig.* 302, which are symmetrically situated as respects the poles, P P. When a magnet is freely suspended it arranges itself north and south, as has been stated. To that pole which is to-

Fig. 302.



How may the polarity of a needle be shown? How may its attraction for iron be shown? Prove that these effects take place through glass, but not through iron. Is the magnetic power equally diffused through a bar? What are the poles? What is the axis? How may it be proved that the poles are the foci of action? How may the magnetic curves be exhibited?

ward the north the name of north pole is given, the other is the south pole.

When, instead of presenting to a suspended needle a piece of iron, we present to it another magnet, phenomena of repulsion as well of attraction ensue—if the north pole of one be presented to the north of the other, repulsion takes place, and the same occurs if two south poles are presented. But if it be a north and a south pole then attraction takes place.

These results may be grouped together under the simple law—"*Like poles repel and unlike ones attract.*"

There is, therefore, an antagonization of effect between opposite magnetic poles. If a key be suspended to a magnet by its north pole, on the approach of the south pole of one of equal force the key drops off.

If we examine the force of a magnet, commencing at either of its poles and going toward its center, the intensity gradually declines. It ceases altogether about midway between the poles. This point is termed the point or line of magnetic indifference.

Magnetism may be excited in both iron and steel; in the former with greater rapidity, in the latter more slowly. The magnetism which soft iron has received it instantly loses on being removed from the source which has given it magnetism; but steel retains its virtue permanently. Soft iron is, therefore, transiently—hard steel permanently magnetic.

When a mass of iron is in contact with the pole of a magnet, it obtains the same kind of magnetism as the pole with which it is in contact throughout its whole mass, and can, in the same manner, communicate a similar quality to a second mass brought in contact with it; and this to a third, and so on. Thus, if from the pole of a magnet a key be suspended, this will suspend a second, and that a third, &c., until the weight becomes too great for the magnet to hold. If, having two or three keys thus suspended, we take hold of the uppermost and gently slide away the magnet, the moment it is removed the keys all fall apart, showing the sudden loss of power in soft iron.

What is the general law of magnetic attractions and repulsions? How does the intensity vary in a magnet? When is the point of magnetic indifference? What is the difference between the magnetism of steel and of iron? Illustrate the communication of magnetism.

But a mass of iron can receive magnetism at a distance from the magnet itself. To this phenomenon the name of induction is given, and the distance through which this effect can take place is called the *magnetic atmosphere.* The general effect of induction may be exhibited by bringing a powerful magnet near a large key, as in *Fig.* 303, when it will be found that the large key will support smaller ones; but as soon as it is removed from the influence of the magnet these all drop off.

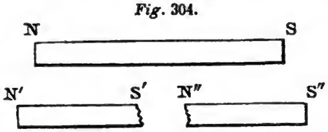
Fig. 303.

When magnetism is thus induced by the action of a given pole, that end of the disturbed body which is nearest to the pole has an opposite polarity; but the farther end has the same polarity as the disturbing pole.

The force of magnetic action varies with the distance. It has been proved by Coulomb and others, that the intensity of magnetic action is inversely proportional to the square of the distance. At twice a given distance it is, therefore, one fourth, at three times one ninth, &c.

Both magnetic polarities must always simultaneously occur. We can never have north magnetism or south magnetism alone. Thus, if we take a long magnet, N S, *Fig.* 304, and break it in two, we shall not insulate the north polarity in one half and the south in the other, but each of the broken magnets will be perfect in itself, having two poles—one fragment being N′ S′ and the other N″ S″.

Fig. 304.



When the poles of a magnet are polished, and covered with smooth plates of iron, the magnet is said to be armed. The piece of soft iron which passes from pole to pole of a horse-shoe magnet is called a keeper. The power of a magnet is measured by the weight its poles are able to carry.

There are many different ways in which magnetism can be imparted to needles or steel bars, as, for example,

What takes place when a large key suspending several small ones is removed from the magnetic atmosphere? What is induction? What is the nature of the induced polarity? How does the force of magnetic action vary? Can one species of magnetism be separated from the other? What is meant by a magnet being armed? What is a keeper?

by contact, by induction, by certain movements. By the aid of voltaic currents, hereafter to be described, the most intense magnetic power can be communicated.

The process of magnetization by the *single touch* is that in which we place one pole of a magnet in the middle of the steel bar, and, drawing it toward the end, then lifting it up in the air return it to its former position, and repeat the movement several times. The magnet is now to be reversed, and in that position moved to the opposite end of the bar, lifted up in the air, replaced, and the movement many times repeated. The bar thus becomes a magnet, each end having a pole opposite to that by which it was touched. Or we may place two magnets with their opposite poles in the middle of the bar, and then, drawing them apart in opposite directions, the same result arises. A still more powerful magnetism may be given if the bar to be magnetized is laid on the poles of two magnets, so that the contrary pole of the magnets and bar coincide.

In the *double touch* two bar-magnets are so tied together that their opposite poles may be maintained a short distance from one another. This combination is then placed on the middle of the bar to be magnetized, and drawn toward its end; but as soon as it reaches that without passing over it, it is returned to the other end with a reverse motion, and then back again; and after this has been done several times the process is ended by drawing the combination off sideways, when it is at the middle of the bar.

Describe some of the methods by which magnetism may be imparted. Describe the process by single touch. What is that by double touch?

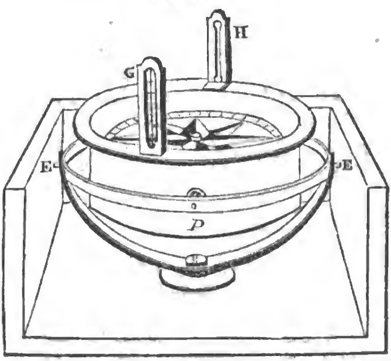
LECTURE LVII.

TERRESTRIAL MAGNETISM.—*Mariner's Compass.—Magnetic Variation.—Lines of Equal Declination.—Dipping-Needle.—Lines of Equal Dip.—Magnetic Terrestrial Poles.—The Earth's Inductive Action.—Lines of Equal Intensity.—Magnetometers.—Secular and Diurnal Variation.—Irregular Disturbances.—Terrestrial Magnetism due to the Heat of the Sun.*

WHEN a magnetic needle is suspended on a pivot so as to have freedom of motion horizontally, it sets itself nearly in a direction north and south, and constitutes a compass.

In the mariner's compass a light card is attached to the needle; on it there is drawn a circle divided into thirty-two parts. This accompanies the motion of the needle, and as the instrument is constantly liable to be thrown into a variety of positions by the motions of the ship, it is supported in gymbals, as shown in *Fig.* 305. This con-

Fig. 305.



trivance consists of two pair of pivots, E E, P P, set upon rings at right angles to one another, and the bottom

What is a compass? How is the mariner's compass arranged? What are gymbals?

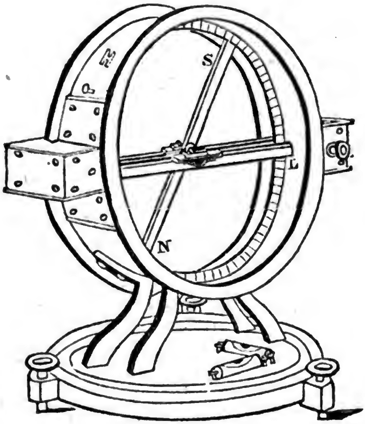
of the compass-box being heavy it is immaterial what position is given to it; it always sets itself with the card in a horizontal plane. Occasionally the box is accommodated with sights, G H.

Accurate observations have shown that the magnetic needle does not, however, point rigorously north and south, except in a few restricted positions, on the earth's surface. But it exhibits in most places a declination or variation to the east or west of the true point. If the places in which there is no declination be connected together, the line running through them is called a line of no declination, and of these there are two, one the American and the other the Asiatic. These have a general direction from the north to the south.

By lines of equal declination we mean those lines which pass through places where the amount of declination is equal. They are irregular in their form, but have a relation to the magnetic poles. The position of these, as well as of the former lines, is not stable: it varies in the course of time.

When a needle is arranged on a horizontal axis, so as

Fig. 306.



Does the compass point accurately north and south? What is a line of no declination? How many are there? What is their direction? What are lines of equal declination? Are these regular curves?

to move in a vertical plane, it constitutes a dipping-needle, of which a representation is given in *Fig.* 306. The points of the needle, N S, traverse over a circle divided into degrees, and the angle which such a needle makes with a horizontal line is the angle of the dip. In the northern hemisphere the north pole dips; near the equator the needle has no dip; and in the southern hemisphere the south pole dips.

The dip of the needle was first discovered by Norman, who noticed that, after a mariner's compass-needle was magnetized it lost its horizontality, and required a little wax or some small weight on the opposite side to restore it to its true position.

The dip of the needle differs in different places. Those points of the earth where there is no dip being connected together by a line, give what is termed the magnetic equator. It is a very irregular curve which cuts the geographical equator in two places, so that in the western hemisphere it is south of the equator, and in the eastern north. Lines which connect places where the dip is equal are called lines of equal dip; they observe a general parallelism to the magnetic equator.

All the magnetic phenomena exhibited by the earth in their general features answer to what ought to take place were the earth itself a great magnetic mass, with its poles near, but not coincident with the geographical poles. On this principle the polarity and the dip of the needle are both readily explained. Of course the north pole of the earth possesses analogous properties to the south pole of the suspended needle, and *vice versa*. Formerly it was believed that there existed two terrestrial poles in each hemisphere; but there is reason now to suppose that there is but one. That in the northern hemisphere was reached by Sir James Ross in 1833.

This general similitude of the earth's action to that of a magnet is still further borne out by the inductive influence of the earth. This may be shown in a very striking manner, by taking a bar of soft iron and bringing it near

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What is a dipping-needle? How does it act in the north and in the south hemispheres? How was the dip first discovered? What is the magnetic equator? What is its course? What are lines of equal dip? What do the phenomena of terrestrial magnetism answer to? How many magnetic poles are there? Has the magnetic pole ever been reached?

a suspended needle. So long as the bar is in a horizontal position, and at right angles to the middle of the needle, the latter is unaffected; but, on turning the bar, so that its length may coincide with the line of dip, its lower pole will repel the north pole of the needle, showing that it has north polarity; but it will attract the south pole. And this condition remains so long as the bar remains in its position; but, on turning it over, and reversing its position, its magnetism is instantly reversed, showing that the whole action is due to the power of the earth.

Like the declination and the dip, the absolute intensity of the earth's magnetism varies very much in different places; at the magnetic equator being most feeble, and gradually increasing as we go the poles. Lines connecting places where the intensities are equal are *lines of equal intensity.* This absolute intensity is estimated by the number of oscillations which a magnet makes in a given time, being thus directly as the number of oscillations made in one minute. The declination-needle gives us, by its oscillations, a measure of that portion of terrestrial magnetism which acts horizontally, the dipping-needle that which acts vertically; but it may be shown that the effect of either of these is proportional to the absolute intensity. To measure these effects, instead of small and light needles being used, bars of several pounds weight are employed. They are called magnetometers.

The declination, the dip, and the intensity all undergo variations at the same place; some of which are regular and others irregular—some occurring through long periods of time, and others at short intervals. In the year 1657, the declination needle pointed due north in London; it then commenced moving westward, and continued to do so till the close of last century. Its variation is now decreasing. The daily variation consists of an oscillation eastward or westward of the mean position, the amount of which varies with the times of the day, and is different in different places. Generally the greatest declination eastward is between six and nine in the morning,

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How may the earth's inductive action be established by experiment? Is the absolute intensity variable? How is it estimated? What do the declination and dipping-needles respectively indicate? What are magnetometers? Are the declination, dip, and intensity constant in amount? What variations have been observed in the needle at London?

and westward about one in the afternoon, returning toward the east until eight P. M. It is never more than a few minutes; and the needle is stationary at night. Changes in the weather and the occurrence of storms and clouds have also an influence on the needle. The dipping-needle exhibits similar phenomena; and, as respects the intensity, it is greater in the evening than the morning, and is less in summer than in winter.

Besides these, there are regular disturbances of the earth's magnetism—such, for instance, as those arising from the aurora borealis, which will sometimes deflect the needle several degrees. Over very extensive areas simultaneous disturbances have been noticed, it having been established that the minute and irregular variations take effect at the same instant in places at great distances apart.

There can be no doubt that the magnetism of the earth is very intimately connected with the calorific action of the sun. Thus, the lines of equal dip closely correspond to the lines of equal heat—the northern magnetic pole nearly coincides with the point of minimum heat on the earth's surface. The diurnal variations, in some measure, follow the temperature, as the sun shines on different parts in succession; and the same connection with inequality of heating is traced in the annual variation. When we come to describe thermo-electric currents—currents excited by heat—and trace the effect of these currents on the suspended needle, we shall have a clearer idea of the nature of these obscure phenomena.

What are the diurnal variations? At what periods do they occur? What influence does the aurora borealis exert? What reasons have we for supposing that the magnetism of the earth is connected with the calorific action of the sun?

ELECTRICITY.

LECTURE LVIII.

ELECTRICITY.—*First Discoveries in Electricity.—Leading Phenomena.—Conductors, Non-conductors, and Insulation.—Two Kinds of Electricity.—Vitreous and Positive, Resinous and Negative.—Law of Electrical Attraction and Repulsion.—Plate Machine.—Cylinder Machine.— Miscellaneous Electrical Experiments.— The Two Theories of Electricity.*

MORE than two thousand years ago it was discovered that when amber is rubbed it acquires the property of attracting light bodies. This incident has served to give a name to the agent whose operations we have now to explain, which has been called electricity, from ηλεκτρον, a Greek word, signifying amber.

A great number of other bodies possess the same quality; among these may be mentioned glass, sealing-wax, resin, silk. They, too, when rubbed, can attract light substances, and, when the excitement is vigorous, emit sparks like those which are seen when the back of a cat is rubbed on a frosty night. It is not improbable that it was from observing this singular phenomenon that the Egyptians were induced to regard that animal as sacred.

If a piece of brown paper be thoroughly dried at the fire until it begins to smoke, and then rubbed between woollen surfaces, it will emit sparks on the approach of the finger, attract pieces of light paper, and then repel them. This latter phenomenon is not, however, peculiar to it, but is noticed in the case of all highly-excited bodies.

When were electrical phenomena first observed? What circumstance has given to this agent a name? Mention some other electrics. What experiments may be made with dry brown paper?

Electrified bodies, therefore, exhibit repulsions as well as attractions.

Let there be taken a glass tube, *a b*, *Fig*. 307, an inch in diameter and a foot or more long, closed at the end, *b*, by means of a cork, into which there is inserted a wire with a round ball, *c*. If the tube be excited by rubbing with a piece of dry silk it may be shown that not only does the space rubbed possess the powers of attraction and repulsion, but also the cork and the ball. Nor does it matter how long the wire may be, the electric power is transmitted through the whole of the metal. A metal, therefore, can conduct electricity.

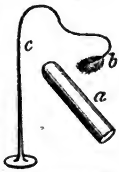
Fig. 307.

But if, instead of a piece of metal, we terminate the glass tube with a rod of glass or sealing-wax, or hang a ball to it by a thread of silk, in all these cases the electric power cannot pass. Such substances are, therefore, non-conductors of electricity.

When electricity is communicated to a body which is supported on any of these non-conducting substances, its escape is cut off, and the body is said to be *insulated*.

From a silk thread which is fastened to a stand, *c*, *Fig*. 308, let there be suspended a feather, *b*; let this be electrified by a glass rod, *a*, highly excited. The feather is at first attracted and then repelled. On the approach of the excited glass it instantly recedes, attempting, as it were, to get out of its way. Now, instead of the glass rod, *a*, let us present a stick of excited sealing-wax, or a roll of sulphur—the feather is instantly attracted, and, therefore, this remarkable experiment proves that the electric virtue which emanates from excited bodies is not always the same, and that a body which is repelled by excited glass is attracted by excited wax.

Fig. 308.



Extensive inquiry has shown, that in reality there are two species of electricity, to which names have therefore

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What results may be shown by the instrument, *Fig*. 307? How may it be shown that metals conduct electricity? How may it be proved that other bodies are non-conductors? What is meant by insulation? Prove that there are two different sorts of electricity? What names have been given to them?

been given. To one—because it arises from the friction of glass—vitreous electricity; and to the other, which arises under similar circumstances from wax, resinous electricity.

The relations of these electrical forces to one another, as respects attraction and repulsion, constitute the fundamental law of this department of science. That general law, briefly expressed, is—"Like electricities repel and unlike ones attract." That is to say, two bodies which are both vitreously or both resinously electrified, will repel each other; but if one is vitreous and the other resinous, attraction takes place. To the two different species of electricity synonymous designations are sometimes applied. The vitreous is called *positive*, and the resinous *negative* electricity.

Fig. 309.

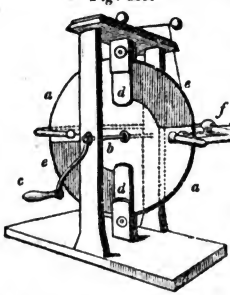
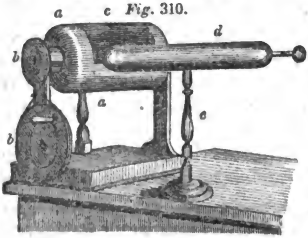


Fig. 310.



For the sake of observing electrical phenomena more readily, instruments have been invented, called electrical machines. They are of two kinds: the plate machine and the cylinder; they derive their names from the shape of the glass employed to yield the electricity. The plate machine, *Fig*. 309, consists of a circular plate of glass, *a a*, which can be turned upon an axis, *b*, by means of a winch, *c;* at *d* is a pair of rubbers, which compress the glass between them, and a piece of oiled silk extends over the glass plate, as shown at *e;* in the same manner, on the opposite side of the plate, there is another pair of rubbers, *d*, and an oiled silk, *e; f* is the prime conductor, which gathers the electricity as the plate revolves. It must be supported on an insulated stem.

The cylinder machine is

What is the general law of electrical attraction and repulsion? What names are given to the two sorts of electricity? Describe the plate machine. Describe the cylinder machine.

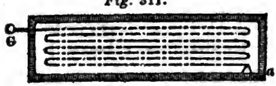
represented at *Fig.* 310. It consists of a glass cylinder, *a a*, so arranged that it can be turned on its axis by the multiplying-wheel, *b b*. The rubber bears against the glass on the opposite side to that seen in the figure, and the oiled silk is shown at *c; d* is the prime conductor, usually a cylinder with rounded ends, made of thin brass, and *e* its insulating support.

Of these machines the plate is commonly the most powerful. It is more liable to be broken than the cylinder, from the disadvantageous way in which the power to turn it round is applied.

To bring an electrical machine into activity, it must be thoroughly dried; but a plate machine should never be set before the fire to warm, or it will almost certainly crack. The rubbers are to be spread over with a little Mosaic gold, or amalgam of zinc, and the stem of the conductor made dry. If the rubbers of the machine are not in connection with the ground, there must be a chain hung from them to reach the table. Then, when the instrument is in activity, on presenting the finger to the prime conductor a succession of sparks is emitted, attended with a crackling sound.

A great many beautiful experiments may be made by the aid of this machine. They are for the most part illustrations of the luminous effects of the spark, attractions and repulsions, and certain physiological results, as the electrical shock.

Fig. 311.



If there be pasted on a slip of glass a continuous line of tin foil, as shown in *Fig.* 311, and then letters be cut out of it with a sharp knife, on presenting the ball, G, which communicates with the tin foil to the prime conductor, and touching the point, *a*, with the finger, the electric fluid will run along the metallic line, leaping over each interspace, in the form of a short but brilliant spark, and marking out the letters in a beautiful manner.

A tube several feet long, with a ball at one end and a stop-cock at the other, is to be exhausted of air. On presenting the ball to the prime conductor, the electricity

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Which of the two is more powerful? How are they brought into action? How may words be written by the electric spark? What phenomena are exhibited by an exhausted tube?

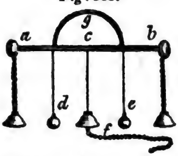
passes down the whole length of the exhausted tube as a pale milky flame, but giving now and then brilliant flashes, especially when the tube is touched. The phenomenon has some resemblance to that of the Northern lights.

Fig. 312.

Between two metallic plates, *a b*, *Fig.* 312, of which *a* is hung by a chain to the prime conductor, and *b* supported on a conducting stand, let some figures, made of paper, pith, or other light body, be placed. The plates may be three or four inches apart. On throwing the machine into activity the figures are alternately attracted and repelled, and move about with a dancing motion.

From a brass rod, *a c b*, *Fig.* 313, which may be hung by an arch, *g*, to the prime conductor, three bells are suspended—two from *a* and *b* by chains, and the middle one, *c*, by a silk thread—between the bells two little metallic clappers, *d e*, are hung by silk, and from the inside of the middle bell a chain, *f*, hangs down upon the table. On setting the electrical machine in activity, the clappers commence moving and ring the bells. This instrument has been employed in connection with insulated lightning-rods, to give warning of the approach of a thunder-cloud.

Fig. 313.



To account for the various phenomena of electricity, two theories have been invented. They pass under the names of Franklin's theory, or the theory of one fluid, and Dufay's theory, or the theory of two fluids.

Franklin's theory is, that there exists throughout all space an ethereal and elastic fluid, which is characterized by being self-repulsive—that is, each of its particles repels the others; but it is attractive of the particles of all other matter. To this the name of electric fluid has been given. Different bodies are disposed to assume particular or specific quantities of this fluid, and when they have the amount that naturally belongs to them, they are said to be in a *natural state* or *condition of equilibrium*. But if more than

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Describe the experiment of the dancing figures. Describe the electrical bells. For what purpose have they been used? How many theories of electricity are there? What is Franklin's theory? In what consists the natural, the positive, and negative state of bodies according to it?

the natural quantity is communicated to them, they become *positively electrified;* and if they have less than their natural quantity, they are *negatively electrified.*

The theory of two fluids is, that there exists an ethereal medium, the immediate properties of which are not known. It is composed of two species of electricity—the positive and the negative—each of these being self-repellent, but attractive of the other kind. Bodies are in a *neutral* or *natural state* or *condition of equilibrium,* when they contain equal quantities of the two electricities; and they are *positively electrified* when the positive is in excess, and *negative* when the negative is in excess.

Of these two theories, it appears that the latter will account for the greater number of phenomena.

LECTURE LIX.

INDUCTION, DISTRIBUTION, AND MEASUREMENT OF ELECTRICITY.—*Electrical Induction.—The Leyden Jar.—Its Effects.—Dr. Franklin's Discovery.—The Lightning-Rod.—Distribution of Electricity.—Pointed Bodies.—Velocity of Electricity.—Modes of Developing Electricity.—Zamboni's Piles.—Perpetual Motion.—Electroscopes.—Electrometers.*

BY electrical INDUCTION is meant that a body in an electrified state is able to *induce* an analogous condition in others in its neighborhood without being in immediate contact with them.

This effect arises from the general law of attraction and repulsion; for the natural condition of bodies is such that they contain equal quantities of positive and negative electricity; and, when this is the case, they are said to be in the neutral state, or in a condition of equilibrium.

When, therefore, an electrified body is brought into the neighborhood of a neutral one, both being insulated, disturbance immediately ensues. The electrified body separates the two electricities of the neutral body from

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What is Dufay's theory? How does it account for the corresponding states of bodies? What is meant by electrical induction? What is the natural condition of bodies? How does an electrified body disturb a neutral one?

each other, repelling that of the same kind, and attracting that of the opposite. Thus, if a body electrified positively be brought near one that is neutral, the positive electricity of this last is repelled to the remoter part, but the negative is attracted to that part which is nearest the disturbing body.

The Leyden jar, *Fig*. 314, is a glass jar, coated on the inside and outside with tin foil to within an inch or two of the edge. Through the cork which closes the mouth a brass wire reaches down, so as to be in contact with the inside coating, and terminates at its upper end in a ball. On connecting the outside coating with the ground, and presenting the ball to the prime conductor, a large amount of electricity is received by the machine; and if it be touched on the outside by one hand, and communication be made with the ball by the other, a very bright spark passes, and the electric shock is felt.

Fig. 314.

The mechanical effects of lightning may be represented in a small way by this instrument. On passing a strong shock through a piece of wood it may be torn open, and other resisting media may be burst to pieces. The shock passed through a card perforates it.

Dr. Franklin discovered the identity of lightning and electricity. He established this important fact by raising a kite in the air during a thunder-storm. The string of the kite, which was of hemp, terminated in a silken cord, and at the point where the two were attached a key was hung. The electricity, therefore, descended down the hempen string, but was insulated by the silk, and on presenting a finger to the key, sparks in rapid succession were drawn. It is on this fact that the lightning-rod for the protection of buildings depends. A metallic rod projects above the top of the building, and descends down to a certain depth in the ground, offering, therefore, a free passage for the electric fluid into the earth.

When electricity is communicated to a conducting

Describe the Leyden jar. How is it charged and discharged? What effects may be produced by it? How and by whom was the identity of lightning and electricity proved? What is the principle of the lightning-rod?

body it resides merely upon the surface, and does not penetrate to any depth within. In the case of spherical bodies, this superficial distribution is equal all over; but when the body to which the electricity is communicated is longer in one direction than the other, the electricity is chiefly found at its longer extremities, the quantity at any point being proportional to its distance from the center.

These principles may be very well illustrated by taking a long strip of tin foil, so arranged as to be rolled and unrolled upon a glass axis, and connected with a pair of cork balls, the divergence of which shows its electrical condition. If, now, to this, when coiled up, a sufficient amount of electricity is communicated to make the balls diverge, on pulling out the tin foil, so as to have a larger surface, they will collapse; but on winding the foil up again they will again diverge, showing that the distribution of electricity is wholly superficial, and that when a given quantity is spread over a large surface it necessarily becomes weaker in effect.

In the case of pointed bodies, the length of which is very great compared with their other dimensions, the chief accumulation of electricity takes place upon the point. When a needle is fastened upon a prime conductor, this accumulation becomes so great that the fluid escapes into the air, and may be seen in the dark in the form of a luminous brush. Or if, on the other hand, a needle be presented to a prime conductor it withdraws its electricity from it, and the point becomes gilded with a little star.

The electric fluid moves with prodigious rapidity. It has a velocity greatly exceeding that of light. In a copper wire its velocity is 288,000 miles in one second.

There are many different ways in which electricity may be developed. In the processes we have hitherto described it originates in friction. And, as one kind of electricity can never make its appearance alone, but is always accompanied with an equal quantity of the other,

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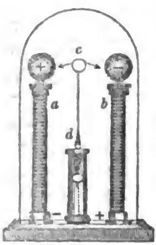
Does electricity reside on the surface or in the interior of bodies? How is its distribution dependent on their figure? How may it be proved that electricity is distributed superficially? What is the effect of pointed bodies? How may a brush and a star of light be exhibited? What is the velocity of the electric fluid? By what processes may electricity be developed? Can one kind of electricity be obtained without the other?

we uniformly find that the rubber and the surface rubbed are always in opposite states—if the one is positive the other is negative. It is on this principle that many machines are furnished with means of collecting the fluid from the prime conductor or the rubber, and, therefore, of obtaining the positive or negative electricity at pleasure.

Electricity may also be developed by heat. The tourmaline, a crystalized gem, when warmed, becomes positive at one end and negative at the other. Changes of form and chemical changes of all kinds give rise to electric development.

Zamboni's electrical piles are made by pasting gold leaf on one side of a sheet of paper and thin sheet zinc on the other, and then punching out of it a number of circular pieces half an inch in diameter. If several thousands of these be packed together in a glass tube, so that their similar metallic faces shall all look the same way, and be pressed tightly together at each end by metallic plates, it will be found that one extremity of the pile is positive and the other negative; and that the effect continues for a great length of time. *Fig.* 315 represents a pair of these piles, arranged so as to produce what was, at one time, regarded as a perpetual motion. Two piles, *a b*, are placed in such a position that their poles are reversed, and between them a ring or light ball, *c*, vibrates like a pendulum on an axis, *d*. It is alternately attracted to the one and then to the other, and will continue its movements for years. A glass shade is placed over it to protect it from external disturbance.

Fig. 315.



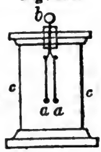
The purposes of philosophy require means for the detection and measurement of electricity. The instruments for these uses are called electroscopes and electrometers; they are of different kinds.

A pair of cork balls, *a a*, *Fig.* 316, suspended by cotton threads so as to hang parallel to one another, and be in metallic communication with the ball, *b*, furnish a sim-

What are the phenomena of the tourmaline? What are Zamboni's electrical piles? How may these be made to furnish an apparent perpetual motion?

ple instrument of the kind. If any electricity is communicated to *b*, the balls participate in it, and as bodies electrified alike repel, these recede from each other. The amount of their divergence gives a rough estimate of the relative quantity of electricity. All delicate electrometers should be protected from currents in the air by means of a glass cylinder or shade, as *c c*.

Fig. 316.



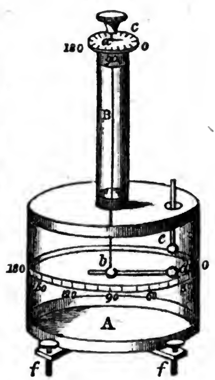
The gold leaf electroscope differs from the foregoing only in the circumstance that, instead of a pair of threads and cork balls, it has a pair of gold leaves, the good conducting power and extreme flexibility of which adapt them well for this purpose.

Fig. 317.

The quadrant electrometer, *Fig.* 317, is formed of an upright stem, *a b*, on which is fastened a graduated semicircle of ivory, *c*, from the center of which hangs a cork ball, *d*. As this is repelled by the stem the graduation serves to show the number of degrees. But no quantity of electricity can ever drive it beyond 90°; and, indeed, its degrees are not proportional to the quantities of electricity.

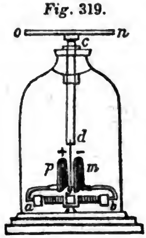
The best electrometer is Coulomb's torsion electrometer, *Fig.* 318, of which a description has been given in Lecture XXIII.

Fig. 318.



The best electroscope is Bohnenberger's. It consists of a small dry pile, *a b*, *Fig.* 319, supported horizontally beneath a glass shade, and from its extremities, *a b*, curved wires pass, which terminate in parallel plates, *p m*. One of these is, therefore, the positive, and the other the negative pole of the pile. Between them there hangs a

Fig. 319.



Describe the cork-ball electroscope. Describe the gold-leaf electroscope. What is the quadrant electrometer? Which is the best electrometer? Which is the best electroscope? Describe it.

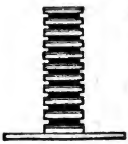
gold leaf, *d g*, which is in metallic communication with the plate, *o n*, by means of the rod, *c*. If the leaf hangs equally between the two plates, it is equally attracted by each, and remains motionless; but on communicating the slightest trace of electricity to the plate, *o n*, the gold leaf instantly moves toward the plate which has the opposite polarity.

LECTURE LX.

THE VOLTAIC BATTERY.—*The Voltaic Pile.—The Trough.—Grove's Battery.—Phenomena of the Battery.—Sparks.—Incandescence.—Decomposition of Water.—Electromotive Force.—Resistance to Conduction.—Power of the Battery.—Phenomena of a Simple Circle.*

THE voltaic pile has a very close analogy in its construction with the dry piles just described. It consists of a series of zinc and copper plates, so arranged that the same order is continually preserved, and between them pieces of cloth, moistened with acidulated water—thus, copper, cloth, zinc; copper, cloth, zinc, &c. There should be from thirty to fifty such pairs to form a pile of sufficient power.

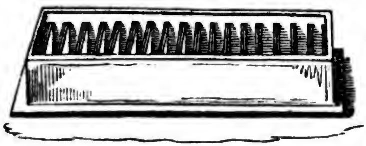
Fig. 320.



When the opposite poles or ends of this instrument are touched, a shock is at once felt. It is not unlike the shock of a Leyden jar; but the pile differs from the electrical machine in the circumstance that it can at once recharge itself, and gives a shock of the same strength as often as it is touched.

As the voltaic battery is now employed for numerous purposes in science, many forms more convenient than that described, have been introduced. In the voltaic trough the zinc and copper plates being soldered together, are let into grooves in a box, as shown in *Fig.* 321, the cells between each pair of plates

Fig. 321.

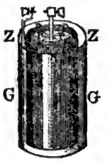


Describe the voltaic pile. Under what circumstances does it give a shock? What is the form given to this instrument in the voltaic trough?

serving to hold the mixture of water and sulphuric acid. Such an instrument is easily brought into activity, and its exciting fluid easily removed.

Of late other more powerful forms of voltaic battery have been invented; such, for instance, as Grove's and Bunsen's. Grove's battery consists of a cylinder of zinc, Z, Z, *Fig.* 322, the surface of which is amalgamated with quicksilver. It is placed in a glass jar, G G. Within this there is a cylinder of porous earthenware, p p, in which stands a sheet of platinum, P P. In Bunsen's battery P is a cylinder of carbon, into which, at *r*, a polar wire can be fastened. The glass cup, G G, is filled with dilute sulphuric acid (a mixture of one of acid to six of water), the porous cylinder is filled with strong nitric acid, and the amalgamated zinc is therefore in contact with dilute sulphuric acid, and the platinum or carbon with nitric acid. By means of the binding screws polar wires may be fastened to the plates, and a number of jars may be connected together so as to form a compound battery. In this case, the wire coming from the zinc of one cup is to be connected with the platinum or carbon of the next, the same arrangement being continued throughout.

Fig. 322.



When several such cups are connected together, and the polar wires of the terminal pairs brought in contact, a bright spark, or rather flame, instantly passes, and when these connecting wires are of copper the color of the light is of a brilliant green. By fastening on one of the polar wires conducting substances of different kinds, they burn or deflagrate with different phenomena, each metal yielding a colored light. If a fine iron or steel wire, in contact with one of the poles, be lowered down on some quicksilver into which the other is immersed, a brilliant combustion ensues—the iron, as it burns, throwing out innumerable sparks; and on pointing the polar wires with pieces of hard-burnt charcoal, on approaching them to each other a spark passes, and the points may now be drawn apart several inches, if the battery is powerful, the

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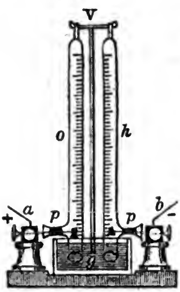
Describe Grove's battery. In this battery how many metals and liquids are employed? What effect ensues when the connecting wires are brought in contact? What phenomena do the different metals exhibit during combustion? What ensues when charcoal-points are employed?

flame still continuing to play between them. This flame, which is arched upward, affords the most brilliant light that can be obtained by any artificial process.

If, between the polar wires of a voltaic battery, a piece of platinum—a metal of extreme infusibility—intervenes, and the metal withstands fusion and is not too thick, it becomes incandescent, and continues so while the current passes.

But by far the most valuable effects to which these instruments give rise are decompositions. If the poles of a battery are terminated with pieces of platinum, and these are dipped in some water, bubbles of gas rapidly escape from each—they arise from the decomposition of the water.

Fig. 323.



The apparatus *Fig*. 323, enables us to perform this experiment in a very satisfactory manner. It consists of two tubes, *o h*, which have lateral openings, *p p*, through which, by means of tight corks, platinum wires, terminated by a little bunch of platinum, may be passed. The tubes, *o h*, are suspended vertically, in a small reservoir of water, *g*, by an upright, V. They are also graduated into parts of equal capacity. By means of the binding screws at *a* and *b* the platinum wires may be connected with the poles of an active battery.

If, now, the two tubes are filled with water and immersed in the trough, and the communications with the battery established, gas rapidly rises in each, and collects in its upper part. In that tube which is in connection with the positive pole of the battery oxygen accumulates, in the other hydrogen. And it is to be observed that the quantity of the latter is equal to twice the quantity of the former gas. Water contains by volume twice as much hydrogen as it does oxygen.

In any voltaic combination, the exciting cause of the electricity, whatever it may be, goes under the name of

Can platinum be made continuously incandescent? Describe the process for the decomposition of water. What are the relative quantities of oxygen and hydrogen gases produced in this experiment?

the electromotive force, and the resistances, which obstruct the motion of the electricity, are termed resistances to conduction.

The electromotive force determines the amount of electricity which is set in motion; and in a voltaic battery the resistances which arise are chiefly due to the imperfect conducting power of the liquid and metalline parts.

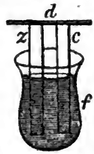
The resistance of the metalline parts is directly as their lengths and inversely as their sections. A wire two feet long resists twice as much as a wire one foot, if their sections are equal; and of two wires that are of an equal length that which has a double thickness or section will conduct twice as well.

The resistance of the liquid parts depends on the distance of the plates from one another—it is inversely as their sections of those parts.

The total force of any voltaic battery may be ascertained by dividing the sum of all the electromotive forces by the sum of all the resistances

The origin of the electrical action of voltaic combinations is, in all probability, due to chemical changes going on in them. The study of a simple voltaic circle throws much light on these facts. If we take a plate of amalgamated zinc, *z*, an inch wide and six long, and a copper plate, *c*, of equal size, and dip them in some acidulated water contained in a glass jar, *f*, they form a simple voltaic circle. It is to be understood that common sheet zinc is easily covered over with quicksilver, or amalgamated, by washing it with sulphuric acid and water in a dish in which some quicksilver is placed.

Fig. 324.



Now, so long as the two plates remain side by side without touching, no action whatever takes place; but if we establish a metallic communication between them by means of the wire *d*, innumerable bubbles of gas escape from the copper, *c*, and the zinc in the mean time slowly corrodes away. On lifting up *d* the action instantly ceases,

What is meant by the term electromotive force? What by resistances to conduction? From what do the resistances chiefly arise? What is the law for the resistance of the metallic parts? What for the liquid? How is the total force of the voltaic battery determined? Describe the apparatus, *Fig.* 324.

on bringing it into contact again the action is re-establish-lished. And if the apparatus is in a dark place whenever *d* is lifted from either plate, *z* or *c*, a small but brilliant electric spark is seen, showing therefore that electricity is the agent at work.

If the gas which rises from the copper plate be examined, it turns out to be hydrogen, and the corrosion of the zinc is due to the combination of that metal with oxygen. Water, therefore, must have been decomposed to furnish these elements. The electric action of the common voltaic circle arises from the decomposition of water.

If the wire *d* be a slender piece of platinum it continues in an ignited condition as long as the apparatus is in activity. The electricity must, therefore, flow in a continuous current; and, as the most powerful voltaic batteries are nothing but combinations of these simple ones, the same reasoning applies to both, and we attribute their action to the same cause—chemical decompositions going on in them, and giving rise to an evolution of electricity which flows in a continuous *current* from end to end of the instrument and back through its polar wires.

A very beautiful process for working in metals, called the electrotype, and founded upon the principles explained in this lecture, has been lately introduced into the arts. When water is submitted to the influence of a voltaic current we have seen that it is resolved into its constituent elements, oxygen and hydrogen, a total separation ensuing, and each of these going to its own polar wire. In the same manner, when a metalline salt transmits the voltaic current, decomposition ensues, the acid part of the salt being evolved at the positive and the metalline part at the negative pole. When the salt has been properly selected the metal is deposited as a coherent mass, and faithfully copies the form of any surface in which the negative pole is made to terminate. Thus, to the polar wire Z, *Fig.* 325, of a simple voltaic battery let there be attached a coin or other object, N, one surface of which has been varnished or covered with some non-

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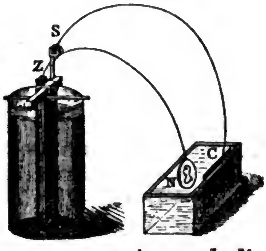
What ensues when a metallic communication is made between the metals? How can it be proved that electricity is concerned in these results? Why do we know that water must have been decomposed? Why do we know that there is a continuous current of electricity passing? On what principles is the electrotype process founded?

conducting material; to the other wire, S, let there be affixed a mass of copper, C, and let the trough, N C, in which these are placed be filled with a solution of sulphate of copper. Now, when the battery is charged, the sulphate of copper in the trough undergoes decomposition, metallic copper being deposited on the face of the coin, N; and as this withdrawal of the metal from the solution goes on, the mass, C, undergoes corrosion, and, dissolving in the liquid, replaces that which is continually accumulating on the face of the coin. When the experimenter judges that the deposit on N is sufficiently thick, he removes it from the trough, and with the point of a knife splits it from the surface of the coin. The cast thus obtained is admirably exact.

Fig. 325.



In the same manner that copper may thus be obtained from the sulphate, so other metals may be used. Casts in gold and silver, and even alloys, such as brass, may be obtained. There is no difficulty in gilding, silvering, or platinizing surfaces, and from a single cast, by using it in turn as a mould, innumerable copies may be taken.

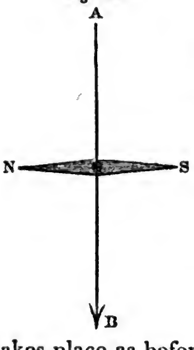
Describe one of the methods for taking casts. Can other metals besides copper be used? Is this process adapted for gilding and silvering?

LECTURE LXI.

ELECTRO-MAGNETISM.—*Action of a Conducting Wire on the Needle.—Transverse Position assumed.—Effects of a Bent Wire.—The Multiplier.—Astatic Galvanometer. Electro-Magnet.—Rotatory Movements.—Attraction and Repulsion of Currents.—Electro-Dynamic Helix.—Electro-Magnetic Theory.*

WHEN a magnetic needle, having freedom of motion upon its center, is brought near a wire through which an electric current is passing, the needle is deflected and tends to move into such a position as to set itself at right angles to the wire.

Fig. 326.



Thus, let there be an electric current moving in the wire A B, *Fig.* 326; in the direction of the arrow, and directly over the wire and parallel to it, let there be placed a suspended needle; as soon as the current passes in the wire, the needle is deflected from its north and south position, and turns round transversely, and if the current is strong enough the needle comes at right angles to the wire.

Now, every thing remaining as before, let the current pass in the opposite direction, the deflection takes place as before, only now it is also in the opposite direction.

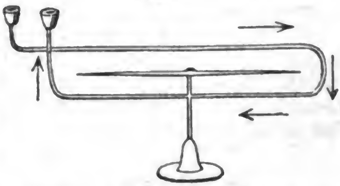
If the needle be placed by the side of the wire the same effect is observed. On one side it dips down and on the other it rises up.

What effect ensues when a magnetic needle is brought near a conducting wire? How may it be proved that the direction of the motion depends on the direction of the current? What takes place when the needle is at the side of the wire?

In whatever position the needle is placed as respects the conducting wire it tends to set itself at right angles thereto. This discovery was made by Oersted in 1819.

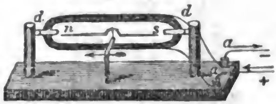
From the foregoing experiments it will appear that if a wire be bent into the form of a rectangle, as represented in *Fig.* 327, and an electric current be made to flow round it in the direction of the arrows, all the parts of the current tend to move a needle in the interior of such a rectangle in the same direction, and, therefore, it will be much more energetically disturbed than by a single straight wire.

Fig. 327.



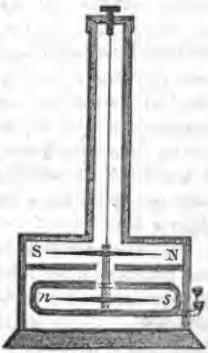
If the wire, instead of making one convolution or turn, is bent many times on itself, so that the same current may act again and again upon the needle, the effect of a very feeble force may be rendered perceptible. On this principle the galvanometer is constructed. A fine copper wire, wrapped with silk, is bent on itself many times, forming a rectangle, *d d*, *Fig.* 328; the two projecting ends, *a a*, dip into mercury-cups, by which they may be connected with the apparatus, the electric current of which is to be measured. In the interior of the rectangle, supported on a pivot, is a magnetic needle, *n s*, the deflections of which measure the current.

Fig. 328.



A still more delicate instrument is made by placing two needles, with their poles reversed, on the same axis, N S, *s n*, suspending them by a fine thread in such a way that one

Fig. 329.

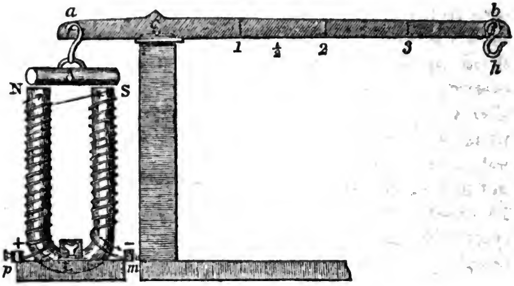


By whom were these facts discovered? What effect is there on a needle in the interior of a rectangle? What is the effect when the wire makes many convolutions? Describe the deflecting galvanometer.

of the needles is in the inside of the rectangle and the other above. If the needles are of equal power the combination is astatic—that is, not under the magnetic influence of the earth; but both of them are moved in the same direction by the passage of the current. Such an instrument is called an astatic galvanometer.

When an electric current, moving in a wire, is made to pass round a piece of soft iron, so long as the current continues the iron is magnetic; but the moment the current ceases the iron loses its magnetism. If, therefore, a bar of soft iron be bent into the form N S, *Fig.* 330, and

Fig. 330.



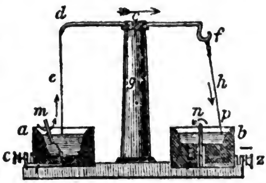
there be wound round it a copper wire in a continuously spiral course, the strands of the wire being kept from touching one another, and also from contact with the iron, by being covered with silk, whenever a current is passed through the wires by the aid of the binding-screws, *p m*, the iron becomes intensely magnetic. The amount of its magnetism may be measured by attaching the keeper, A, to the arm of a lever, *a b*, which works on a fulcrum, *c*; *h* is a hook by which weights may be suspended. In this way magnets have been made which would support more than a ton.

Mr. Faraday discovered that rotatory movements could be produced by magnets round conducting wires; and, conversely, that conducting wires would rotate round magnets. Both these facts may be proved at once by the instrument *Fig.* 331. On the top of a pillar, *g c*, a strong copper wire, bent as in the figure, at *d f*, is fastened.

Describe the astatic galvanometer. How may transient magnetism be communicated to an iron bar? Describe the instrument, *Fig.* 330.

To the crook at *f* a fine platina wire, *h*, hangs by a loop, on which it has perfect freedom of motion. Its lower end, *p*, on which is a small glass bead, dips under some mercury in a reservoir, *b*, in the center of which a magnetized sewing-needle, *n*, is fastened by means of a slip of copper, which communicates with

Fig. 331.



the binding-screw, *z*. On the arm, *d*, there is soldered inflexibly another platinum wire, *e*, which dips into a mercury reservoir, *a*, which is in metallic connection with the binding-screw *c* by means of a slip of copper. From the center and bottom of this reservoir a magnetized sewing-needle is fixed by means of thin platinum wire, so as to have freedom of motion round *e*. Under these circumstances, if an electric current is passed from *c* along *d*, in the direction of the arrow, to *z*, the magnet, *m*, rotates round the fixed wire in one direction, and the wire, *h*, round the fixed magnet *n* in the other. On reversing the course of the current these motions are reversed.

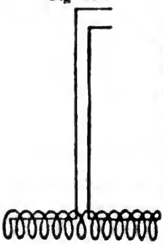
On similar principles all kinds of rotatory, reciprocatory, and other movements may be accomplished, magnets made to revolve on their own axes, and entire galvanic batteries round the poles of magnets.

In frictional electricity we have seen that the fundamental law of action is, that like electricities repel and unlike ones attract. In the same way attractive and repulsive motions have been discovered in the case of currents. If electric currents flow in two wires which are parallel to each other, and have freedom of motion, the wires are immediately disturbed. If the currents run in the same direction the wires move toward each other, if in the opposite the wires move apart. Or, briefly, "*like currents attract, and unlike ones repel.*"

If a wire be coiled into a spiral form, and its ends carried back through its axis, as shown in *Fig.* 332, it forms

How may movements of rotation of wires and magnets round one another be shown? Describe the instrument, *Fig.* 331. What ensues on reversing the current? What is the action of currents on each other? What is the general law of this action?

Fig. 332.



an electro-dynamic helix. If it be suspended with freedom of motion in a horizontal plane, it points as a magnetic needle would no, north and south; or if suspended, so as to move in a vertical plane, it dips like a dipping-needle.

All the properties of a needle may be simulated by such a helix; and if two helices, carrying currents, are presented to each other, they attract and repel, under the same laws that two magnetic bars would do.

If, therefore, we imagine an electric current to circulate round a magnet transversely to its axis, such a supposition will account for all its singular properties.

Anticipating what will have to be said presently as respects thermo-electricity, it may be observed, that if we take a metal ring, and warm it in one point only, by a spirit-lamp, no effect ensues; but if the lamp is moved an electric current runs round the wire in the course the lamp has taken.

As with this metal, wire, and lamp, so with the earth. The sun, by his apparent motion, warms the parts of the earth in succession, and electric currents are generated, which follow his course. We must now call to mind all that has been said respecting the influence of the sun's heat on the magnet, in Lecture LVII. This elucidates the cause of the needle pointing north and south. It comes into that position because it is the position in which the electric currents in it are parallel to those in the earth. This is the position, as has just been explained, that currents will always assume. We see why, at the polar regions, it dips vertically down. It is again that its currents may be parallel with those of the earth; for in those regions the sun performs his daily motion in circles parallel to the horizon. We see, also, that it is for the same cause, in intermediate latitudes, that the needle points north and also dips.

What is an electro-dynamic helix? When two such helices act on each other what phenomena arise? What ensues when a metal ring is warmed at one point by a lamp, and what when the lamp is moved? How do these facts bear on the polarity and dip of the needle? Why does a magnetic needle point north and south? Why does it dip?

This prolific theory likewise includes all the phenomena of Oersted, such as the transverse position a needle takes when under the influence of a conducting-wire; for this is again the position in which the currents of the needle are parallel to that in the wire.

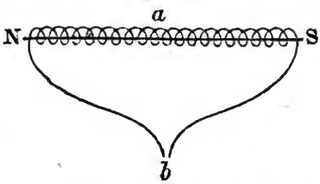
LECTURE LXII.

MAGNETO-ELECTRICITY. — THERMO-ELECTRICITY. — *Production of Electric Currents by Magnets.—Momentary Nature of these Currents.—They give rise to Sparks, Decompositions, &c.—Magneto-Electric Machines.—Induction of Currents by Currents.—Electro-Magnetic Telegraph.—Production of Cold and Heat by Electric Currents.—Thermo-electricity.—Melloni's Multiplier.*

IF an electric current passing round the exterior of a bar of soft iron can convert it into a magnet, we should expect that the converse would hold good, and a magnet ought to be able to generate an electric current in a conducting-wire.

Let there be a helix of copper wire, *a*, *Fig.* 333, the successive strands of which are kept from touching, and let its ends at *b* be brought in contact. If a bar magnet, N S, is introduced in the axis, so long as it is in actual movement an electric current will run through the wire, but as soon as the bar comes to rest the current ceases. On withdrawing the bar the current again flows, but now it flows in the opposite direction.

Fig. 333.



If, therefore, we alternately introduce and remove with rapidity a steel magnet, opposite currents will incessantly run round the helix. If we open the wire at the point *b*, every time the current passes a bright spark is

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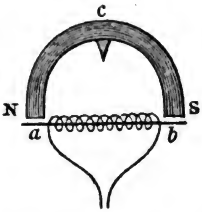
How does this theory include Oersted's phenomena? Can a magnet develop electric currents in a wire? Under what circumstances does this take place? How long does the current continue? Describe the instrument, *Fig.* 333.

seen; or if the two separated ends dip into water it undergoes decomposition.

Fig. 334.



The same results would, of course, occur, if, instead of introducing and removing a permanent steel magnet, we continually changed the polarity of a stationary soft iron bar. Thus if *a b*, *Fig.* 334, be a rod of soft iron, surrounded by a helix, and there be taken a semicircular steel magnet, N *c* S, which can be made to revolve on a pivot at *c*—things being so arranged that its poles, N and S, in their revolutions, just pass by the terminations of the bar, *a b*—the polarity of this bar will be reversed every half revolution the magnet makes, and this reversal of polarity will generate electric currents in the wire. To instruments constructed on these principles the name of magneto-electric machines is given.

The peculiarity of these currents is their momentary duration. Hence they have been called momentary currents, and from the name of their discoverer, Faradian currents.

There are a great many different forms of magneto-electric machines. In some, permanent steel magnets are employed; in others, temporary soft iron ones, brought into activity by a voltaic battery.

Fig. 335 represents Saxton's magneto-electric machine. It consists of a horse-shoe magnet, A B, laid horizontally. The keeper, C D, is wound round with many coils of wire, covered with silk. It rotates on an axis, E F, on which it is fixed, by means of a pulley and multiplying-wheel, E G. The terminations of the wire, *h i*, dip into mercury cups at K. When the wheel is set in motion the keeper rotates, its polarity being reversed every half turn it makes before the magnet, and momentary currents run through its wires.

If it is desirable to give the current of a magneto-electric machine great intensity, so as to furnish powerful shocks, or effect decompositions, the wire which is wound

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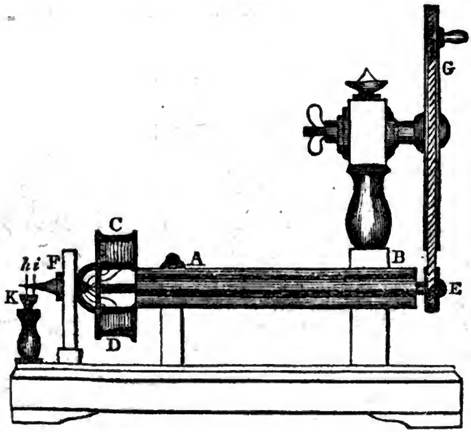
What are magneto-electric machines? What names have their currents received? Describe Saxton's magneto-electric machine. What is the effect of using a long thin and short thick wire?

round the keeper should be thin and long; but for producing incandescence in metals, or for sparks or magnetic operations, the wire should be short and thick.

Fig. 335.



Admitting the theory that all magnetic action arises from the passage of electrical currents, it follows, from the facts just detailed, that an electrical current must have the power of inducing others in conducting bodies in its neighborhood. Experiment proves that this conclusion is correct, and currents so arising are called *induced* or *secondary* currents.

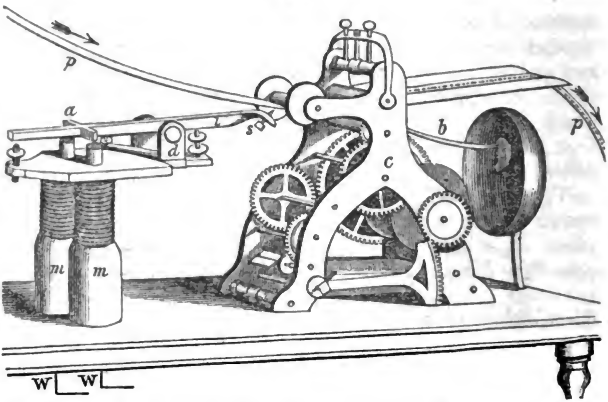
Thus, when two wires are extended parallel to one another, and through one of them an electric current is passed, a secondary current is instantly induced in the other; but its duration is only momentary. It flows in the opposite direction to the primary one. On stopping the primary current, induction again takes place in the secondary wire; but the current now arising has the same direction as the primary one. The passage of an electrical current, therefore, develops other currents in its neighborhood, which flow in the opposite direction as the

How may it be proved that electric currents induce others in their neighborhood? What direction does the induced current take at first, and what at last?

primary one first acts, but in the same direction as it ceases.

Morse's electro-magnetic telegraph is essentially a horse-shoe of soft iron, made temporarily magnetic by the passage of a voltaic current. In *Fig*. 336, *m m* represent

Fig. 336.



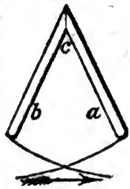
the poles of the magnet, wound round with wire; at *a* is a keeper, which is fastened to a lever, *a l*, which works on a fulcrum, at *d*; the other end of the lever bears a steel point, *s*, which serves as a pen. At *c* is a clock arrangement for the purpose of drawing a narrow strip of paper, *p p*, in the direction of the arrows. W W are the wires which communicate with the distant station. As soon as a voltaic current is made to pass through these wires, the soft iron becomes magnetic, and draws the keeper, *a*, to its poles; and the other end of the lever, *l*, rising up, the point *s* is pressed against the moving paper and makes a mark. When the lever first moves it sets the clock machinery in motion, and the bell, *b*, rings to give notice to the observer. When the distant operator stops the current, the magnetism of *m m* ceases, and the keeper, *a*, rising, *s* is depressed from the paper. By letting the current flow round the magnet for a short or a longer time a dot or a line is made upon the paper—and

Describe Morse's telegraph. How are the dots and lines which compose the telegraphic alphabet made by the machine?

the telegraphic alphabet consists of such a series of marks. It is not necessary to use two wires to the instrument; one alone is commonly employed to carry the current to the magnet; it is brought back through the earth.

If a bar of bismuth, *b*, *Fig.* 337, and one of antimony, *a*, be soldered together at the point *c*, and by means of wires attached to the other ends, a feeble voltaic current is passed from the antimony to the bismuth, heat will be generated at the junction, *c;* but if the current is made to pass from the bismuth to the antimony, cold is produced, so that if an excavation be made at *c*, and a little water introduced in it it may be frozen.

Fig. 337.

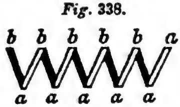


The converse of this also holds good. If we connect the free terminations of *a* and *b*, by means of a wire, and raise the temperature of the junction *c*, an electric current sets from the bismuth to the antimony; but if we cool the junction the current sets in the opposite way. To these currents the name of thermo-electric currents is given.

Thermo-electric currents, from the circumstance that they originate in good conductors, possess but very little intensity. They are unable to pass through the thinnest film of water, and, therefore, in operating with them it is necessary that all the parts of the apparatus through which they are to flow should be in perfect metallic contact. The slightest film of oxide upon a wire is sufficient to prevent their entrance into it.

As the effects of the voltaic circle can be increased by increasing the number of pairs forming it, the same is also true for thermo-electric currents. Thus, if we take a series of bars of bismuth and antimony, and solder their alternate ends to one another, as shown in *Fig.* 338, on warming one set of the junctions, the current passes, and is greater in force according as the number of alternations warmed is greater.

Fig. 338.



From their feeble intensity, these currents, when passed through the wire of a multiplying galvanometer, *Fig.* 329,

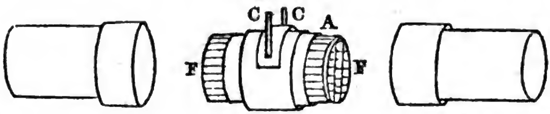
What effects arise from passing feeble electric currents through a pair of bars of bismuth and antimony? What are thermo-electric currents? Why have they so little intensity? How may that intensity be increased?

O

do not give rise to the same effects that are observed in ordinary voltaic currents—they lose as much of their force by the resistance to conduction of the slender wire as they gain by the effect which each coil impresses on the needle. A multiplier, suited for thermo-electric currents, should be made of stout wire, and make but few turns round the needle.

Melloni's thermo-electric pile is represented in *Fig.* 339. It consists of thirty or forty pairs of small bars of

Fig. 339.



bismuth and antimony, with their alternate ends soldered together, forming a bundle, F F. The polar wires, C C, projecting, are put in communication with the multiplier. To each end of the pile brass caps, as seen in the figure, fit. These serve to cut off the disturbing influence of currents of air; and now if the hand or any other source of heat be presented to one side of the pile, the needle of the galvanometer immediately moves, and the amount of its deflection increases with the temperature of the radiant source.

Fig. 340.

It is not necessary to use many alternations, as in the instrument of Melloni. Let a pair of heavy bars of bismuth and antimony, of the shape represented in *Fig.* 340, be soldered by the edges, *a b*, to a circular plate of thin copper, and at the others at *a′ b′*, to semicircular plates, *e f*, having projecting pieces to communicate with the wire of a galvanometer of few convolutions, and the needle of which is nearly astatic. It will be found that extremely minute changes of temperature may be indicated—the combination answering very well instead of Melloni's more costly instrument.

Why does not the common galvanometer increase the effect of these currents? What ought to be the construction of a thermo-electric multiplier? Describe Melloni's instrument. Is it necessary to use so many alternations?

ASTRONOMY.

LECTURE LXIII.

ASTRONOMY.—*The Figure of the Earth.—The Earth Rotates on her Axis.—Illustrations of Diurnal Rotation.—Annual Translation round the Sun.—The Year.—Motions of the Moon.—Planets and Comets.—Astronomical Definitions.*

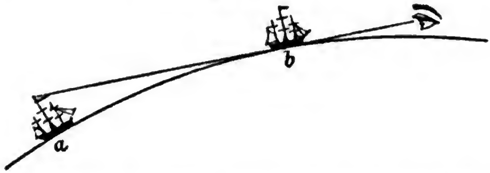
IN the infancy of knowledge the first impression which men entertained respecting the form of the earth we inhabit, was that it is an indefinitely-extended plane, the more central portions being the land, surrounded on all sides by an unknown expanse of sea. Many natural phenomena soon corrected these primitive ideas, and almost as far back as historic records reach, philosophers had come to the conclusion that our earth in reality is of a round or globular form.

To this conclusion a consideration of the daily phenomena of the starry firmament would naturally lead. Every evening we see the stars rising in the east, and as the night goes on, passing over the vault of the sky, and at last setting in the west. During the day the same is also observed as respects the sun. And as these are events which are taking place day after day, in succession, and no man can doubt that the objects which we see to-day are those which we saw yesterday, it necessarily follows, that after they have sunk under the western horizon, they pursue their paths continuously, and that the earth neither extends indefinitely in the horizontal direction, nor vertically downward, but that she is of limited dimensions on all sides.

What was probably the primitive idea respecting the figure of the earth? How may it be proved that the earth is limited on all sides?

Where the prospect is uninterrupted, as at sea, we are further able not only to verify the foregoing conclusion, but also to obtain a clearer notion of the figure of the earth. Thus, as is seen in *Fig.* 341, let an observer be

Fig. 341.



watching a ship sailing toward him at sea. When she is at a great distance, as at *a*, he first perceives her topmast, but as she approaches from *a* toward *b*, more and more of her masts come into view, and finally her hull appears. When she arrives at *b* she is entirely visible. Now, as this takes place in whatever direction she may approach, whether from the north, south, east, or west, it obviously points out the globular figure of the earth. In the distant position, more or less of the ship is obscured by the intervening convexity—a phenomenon which never could take place were the earth an extended plane.

This great truth, though admitted by philosophers in ancient times, fell gradually into disrepute during the middle ages; it was re-established at the restoration of learning only after a severe struggle. It is now the basis of modern astronomy.

The spheroidal figure being therefore received as a demonstrated fact, it is next to be observed that the earth is not motionless in space, but in every twenty-four hours turns round once upon her axis. That such a motion actually occurs is clear from the fact of the rising and setting of the celestial bodies.

To an observer at the equator, the stars rise in the eastern horizon and set in the western, continuing in view for twelve hours, and being invisible for twelve. At the

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What facts prove that she is of a round or globular form? When was the globular form of the earth denied, and when finally established? Has the earth a motion on her axis? In what time is it performed? What are the phenomena of the rising and setting of the stars at the equator and the poles?

pole the rising or setting of a star is a phenomenon never seen; but these heavenly bodies seem to pursue paths which are parallel to the horizon. In intermediate latitudes a certain number of stars never rise or set, while others exhibit that appearance. In any of these positions in our hemisphere the motion of the heavens seems to be round one, or, rather, two points, situated in opposite directions; to one of them the name of the north, and to the other of the south pole is given. These are the points to which the poles of the earth are directed.

When observations are made for some days or months in succession, we find that there are motions among the celestial bodies themselves which require to be accounted for. First, we observe that the sun does not remain stationary in a fixed position among the stars, but that he has an apparent motion; and that after the lapse of a little more than three hundred and sixty-five days he comes round again to his original place. As with the diurnal motion so with this annual. Consideration soon satisfies us that it is not the sun which is in movement round the earth, but the earth which is in movement round the sun. To the period which she occupies in completing this revolution the name of the year is given. Its true length is three hundred and sixty-five days, five hours, forty-eight minutes, forty-nine seconds.

The sun seems, in his daily motion, to accompany the stars; but if we mark the point upon the horizon at which he rises or sets we find that it differs very much for different times of the year. The same observation may be made by observing the length of the shadow of an upright pole or gnomon at midday. Such observations show that there is a difference in his meridian altitude in winter and summer of forty-seven degrees.

The observation of a single night satisfies us that the moon has a motion of her own round the earth. It is accomplished in twenty-seven days, seven hours, and forty three minutes, and is called her *periodical revolution;* but, during this time, the earth has moved a certain distance in the same direction—or, what is the same thing, the sun has advanced in the ecliptic, and before the moon overtakes him, twenty-nine days, twelve hours, and forty-

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What other motion besides this may be discovered? What is the year? What is the month?

four minutes elapse. This, therefore, is termed her *synodical revolution*, or one month.

There are also certain stars, some of which are remarkable for their brilliancy, which exhibit proper motions. To these the name of *planets* is given. And at irregular intervals, and moving in different directions through the sky, there appear from time to time *comets*. Multitudes of these are telescopic, though some have appeared of enormous magnitude.

There are several technical terms used in astronomy which require explanation.

By the *celestial sphere* we mean a sky or imaginary sphere, the center of which is occupied by the earth. On it, for the purposes of astronomy, we imagine certain points and fixed lines to exist.

Those circles whose planes pass through the center of the sphere are called *great circles*. The circumference of each is divided into three hundred and sixty parts, called degrees, and marked (°), each degree into sixty minutes, marked (′), and each minute into sixty seconds, marked (″).

All great circles bisect each other.

Less circles are those whose planes do not pass through the center of the sphere.

The *axis* of the earth is an imaginary line, drawn through her center, on which she turns. The extremities of this line are *the poles*.

A line on the earth's surface every where equidistant from the poles is the *equator*. Circles drawn on the surface parallel to the equator are called simply *parallels*, and sometimes *parallels of latitude*.

At sea, or where the prospect is unobstructed, the sky seems to meet the earth in a continuous circle all round. To this the name of *sensible horizon* is given. The *rational horizon* is parallel to the sensible, and in a plane which passes through the center of the earth.

That point of the celestial sphere immediately overhead is the *zenith*, the opposite point is the *nadir*.

A circle drawn through the two poles and passing through the north and south points of the horizon is *a*

What are the planets? What are comets? What is the celestial sphere? What are great and less circles? What is the axis of the earth? What are the poles, the equator, and parallels of latitude? What is the sensible and what the rational horizon? What is the zenith and the nadir?

meridian. *Hour circles* are other great circles which pass through the poles.

A circle drawn through the zenith and the east and west points of the horizon is the *prime vertical.* Other great circles passing through the zenith are *vertical circles* or *circles of azimuth.*

The *altitude* of a body above the horizon is measured in degrees upon a vertical circle. As the zenith is 90° from the horizon, the altitude deducted from 90° gives the *zenith distance.*

The *azimuth* of a body is its distance from the north or south estimated on the horizon, or by the arc of the horizon intercepted between a vertical circle passing through the body and the meridian.

The *latitude* of a place is the altitude at that place of the pole above the horizon, or, what is the same thing, the arc of the meridian between the zenith of the place and the equator. At the earth's equator the pole is, therefore, in the horizon; at the pole it is in the zenith.

The *longitude of a place* on the earth is the arc of the *equator* intercepted between the meridian of that place and that of another place taken as a standard. The observatory of Greenwich is the standard position very commonly assumed. The *longitude of a star* is the arc of the *ecliptic* intercepted between that star and the first point of Aries.

The *latitude of a star* is its distance from the ecliptic, measured on a great circle passing through the pole of the ecliptic and the star.

The *declination* of a heavenly body is the arc of an hour circle intercepted between it and the equator.

The *ecliptic* is the apparent path which the sun describes among the stars. It is a great circle which cuts the equator in two points, called the *equinoxial points,* because when the sun is in those points the nights and days are equal; one is the vernal, the other the autumnal equinox. From this circumstance the equator itself is sometimes called the *equinoxial line.*

What is a meridian? What are hour circles? What is the prime vertical? What are circles of azimuth? What are altitude and zenith distance? What azimuth, the latitude of a place, and the declination of a heavenly body? What is the longitude of a place and that of a star? What is the ecliptic?

Two points on the ecliptic, 90° distant from the equinoxial points, are the *solstitial points.* When the sun is in one of these it is midsummer, in the other midwinter.

Motions in the direction from west to east are *direct.* Retrograde motions are those from east to west.

The *ecliptic* is divided into twelve equal parts called signs. They bear the following names and have the following signs.

Aries	♈	Libra	♎
Taurus	♉	Scorpio	♏
Gemini	♊	Sagittarius	♐
Cancer	♋	Capricornus	♑
Leo	♌	Aquarius	♒
Virgo	♍	Pisces	♓

Formerly these signs coincided with the constellations of the same name, but owing to the precession of the equinoxes, to be described hereafter, this has ceased to be the case.

Two parallels to the equator—one for each hemisphere—which touch the ecliptic, are called *tropics.* That for the northern hemisphere is the *tropic of Cancer;* that for the south the *tropic of Capricorn.* Two other parallels—one for each hemisphere—as far from the poles as the tropics are from the equator, are the *polar circles,* the northern one is the *arctic,* the southern one the *antarctic.*

The *right ascension* of a heavenly body is the distance intercepted on the equator between an hour circle passing through it and the vernal equinoxial point.

The *astronomical day* begins at noon, the *civil day* at midnight. Both are divided into twenty-four hours, each hour into sixty minutes, each minute into sixty seconds.

By the *orbit* of a body is meant the path it describes. This, in most cases, is an *ellipse.*

The *nodes* are those points where the orbit of a planet intersects the ecliptic. The *ascending* node is that from which the planet rises toward the north, the *descending* that from which it descends to the south; a line joining the two is the line of the nodes.

What are the equinoxial and solstitial points? What are direct and retrograde motions? How is the ecliptic divided? What are the tropics and polar circles? What is right ascension? What is the difference between the astronomical and civil day? What is an orbit? What are the ascending and descending nodes?

LECTURE LXIV.

TRANSLATION OF THE EARTH ROUND THE SUN, AND ITS PHENOMENA.—*Apparent Motion and Diameter of the Sun.—Elliptical Motion of the Earth.—Sidereal Year.—Determination of the Sun's Distance.—Parallax.—Dimensions of the Sun.—Center of Gravity of the Two Bodies.—Phenomena of the Seasons.*

In the last lecture it has been observed that the sun has an apparent motion among the stars in a path called the ecliptic. A line joining that body with the earth, and following his motions, would always be found in the same plane, or, at all events, not deviating from that position by more than a single second.

Observation soon assures us that if we carefully examine the rate of the sun's motion in right ascension, it is far from being the same each day. This want of uniformity might, to some extent, be accounted for by the obliquity of the ecliptic; but even if we examine the motion in the ecliptic itself, the same holds good. The sun moves fastest at the end of the month of December, and most slowly in the end of June.

Further, if we measure the apparent diameter of the sun at different periods of the year, we find that it is not always the same. At the time when the motion just spoken of is greatest, that is during the month of December, the diameter is also greatest; and when in June the motion is slowest, the diameter is smallest. These facts, therefore, suggest to us at once that the distance between the earth and the sun is not constant; but in December it is least, and in June greatest, for the difference in size can plainly be attributable to nothing else but difference of distance.

The annual motion of the sun in the heavens, like his diurnal motion, is, however, only a deception. It is not

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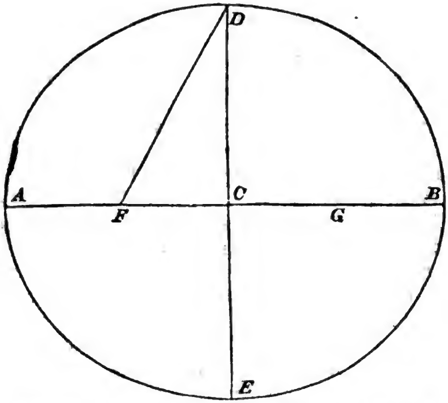
Does the sun move with apparently equal velocity each day? When is his motion fastest and when slowest? Is the sun always of the same size? When is he largest and when smallest? How can we be certain that the earth does not move in a circle round the sun?

the sun which moves round the earth, but the earth which has a movement of translation round the sun, as well as one upon her own axis. The path which she thus describes is not a circle, for in that case, being always at the same distance, the sun would always be of the same apparent magnitude, and his motion always uniform; but it is an ellipse, having the sun in one of its foci. Thus, in *Fig.* 342, let F be the sun, A D B E the elliptic orbit of the earth; it is obvious that as she moves in this path

Fig. 342.



she will be much nearer the focus F occupied by the sun when she arrives at A than when she is at B. To the former point, therefore, the name of *perihelion*, and to the latter of *aphelion* is given; the line A B joining them is called the line of the *apsides*.

The periodic time occupied in one complete revolution is called the *sidereal* year. Its length is 365 days, 6 hours, 9 minutes, 11½ seconds.

The law which regulates the velocity of motion of the earth round the sun was discovered by Kepler. It has already been explained, in speaking of central forces, in Lecture XXI. It is "the radius vector (that is, the line

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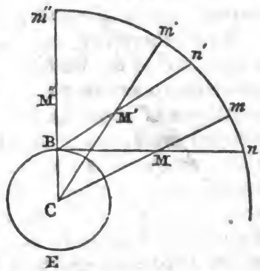
How do we know it is in an ellipse? What are the perihelion and aphelion points? What is the line of the apsides? What is the sidereal year? What is Kepler's law respecting the radius vector?

joining the centers of the sun and earth) sweeps over equal areas in equal times."

With these general ideas respecting the nature of the orbit described by the earth, we proceed, in the next place, to the determination of the actual size of that orbit: in other words, to ascertain the distance between the earth and the sun.

Let C, *Fig.* 343, be the center of the earth, B the position of an observer upon it, and M the sun; the observer, B, will see the sun in the direction B M, and refer him in the heavens to the position, *n*. An observer at C, the center of the earth, would see him in the position C M, and refer him to the point *m*. His apparent place in the sky, will, therefore, be different in the two instances. This difference is called *parallax;* and a little consideration shows that the amount of parallax differs with the place of observation and position of the body observed, being greatest under the circumstances just supposed, when the body is seen in the horizon, and becoming 0 when the body is in the zenith. This diminution of the parallax is exemplified by supposing the sun at M′; the observer at B refers him to *n′*, the observer at C to *m′*, but the angle B M′ C is less than the angle B M C. Again, if the sun be at M″—that is, in the zenith—both observers, at B and C, refer him to *m″*, and the parallax is 0. The horizontal parallax being measured by the angle, B M C is evidently the angle under which the semidiameter of the earth appears, as seen in this instance from the sun.

Fig. 343.



Although we cannot have access to the center of the earth, there are many ways by which the parallax may be ascertained, the result of the most exact of which has fixed for the angle B M C the value of about eight seconds and a half. Now it is a very simple trigonometrical problem, knowing the value of this angle, and the length

What is parallax? Why does the parallax become 0 in the zenith? What is the horizontal parallax in reality? What is the exact value of the parallax?

of the line B C in miles, to determine the line C M. When the calculation is made, it gives about 95,000,000 miles. This, therefore, is the mean distance of the earth from the sun.

Knowing the apparent diameter of an object, and its distance from us, we can easily determine its actual magnitude. Seen from the earth, the sun's apparent diameter subtends an angle of 32′ 3″. The true diameter, therefore, must be 882,000 miles. But the diameter of the earth is short of 8000 miles.

Such, therefore, are the dimensions of the orbit of the earth, and of the bodies concerned in it. We are now in a position to verify all that has been said in respect of the relations of these bodies; for, calling to mind what was proved in Lecture XXI, respecting bodies situated as these are, we see that in strictness the one cannot revolve round the other, but both revolve round their common center of gravity. Recollecting also that the center of gravity of two bodies is at a distance inversely proportional to their weights, and that the sun is 354,936 times heavier than the earth, it follows that this point is only 267 miles from his center. So, therefore, with scarce an error, the center of the sun may be assumed as the center of the earth's orbit, and with truth she may be spoken of as revolving around him.

Occupying such a central position, this enormous globe is discovered to rotate on an axis inclined 82° 40′ to the plane of the ecliptic, making one rotation in twenty-five days and ten hours, in a direction from west to east. This is proved by spots which appear from time to time on his surface, and follow his movements. He is the great source of light and heat to us, and determines the order of the seasons. His weight is five hundred times greater than that of all the planets and satellites of the solar system, though he is not of greater density than water.

In *Fig.* 344 we have a general representation of the appearance of the solar spots. They consist of a dark nucleus, surrounded by a penumbra, and are very varia-

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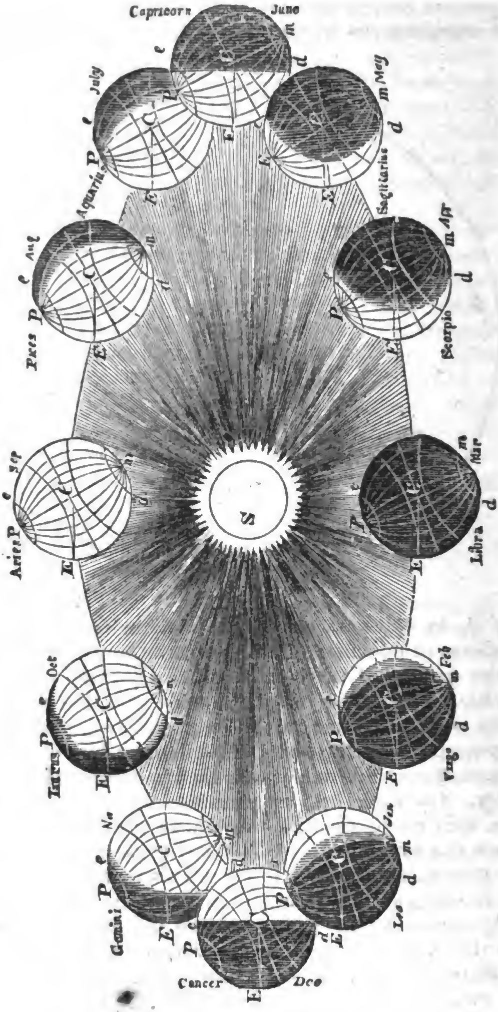
What is the distance of the earth from the sun? What is the actual diameter of the sun? At what distance is the center of gravity of the two bodies from the sun's center? How is it known that the sun rotates on his axis? What is the period of that rotation? Describe the phenomena of his spots.

ble, both in number and size. Sometimes for a considerable period scarce any are seen, and then they occur in great numbers in irregular clusters. Their size varies

Fig. 344.

from $\frac{1}{25}$ to $\frac{1}{500}$ part of the sun's diameter. They are, therefore, of enormous dimensions, often greatly exceeding the surface of the earth. Their duration is also very variable. Some have lasted for ten weeks, but more commonly they disappear in the course of a month or less. They seem to be the seats of violent action, undergoing great changes of form, not only in appearance, but also in reality. On their first appearance on the sun's eastern edge, they move slowly—they move rapidly as they approach the middle of his disc, and move slowly again as they pass to the western edge. This is, however, an optical illusion, due to the globular figure of the sun. They rarely appear at a greater distance than from 30° to 50° from the sun's equator, and cross his disc in thirteen days and sixteen hours. Their apparent revolution is, therefore, twenty-seven days and eight hours; and, making allowance for the simultaneous movement of the earth, this

Fig. 345.


Capricorn
June
July
Aquarius
May
Sagittarius
Apr
Scorpio
Pisces
Sep
Aries
Mar
Libra
Oct
Taurus
Feb
Virgo
Gemini
Jan
Leo
Cancer
Dec
S

gives for the sun's rotation on his axis twenty-five days and ten hours.

To explain the occurrence of the seasons—spring, summer, autumn, and winter—it is to be understood that the earth's axis of rotation, for the reasons explained in Lecture XXI, always points to the same direction in space, and, therefore, as the earth is translated round the sun, is always parallel to itself.

Let, therefore, *S*, *Fig.* 345, be the sun, and *E E E*, &c., the positions the earth respectively occupies in the months marked in the figure. Her position is, therefore, in Libra at the vernal equinox, in Aries the autumnal, in Capricorn at the summer, and in Cancer at the winter solstice. In these different positions, *P m* represents the axis of the earth always parallel to itself, as has been said. Now, from the globular form of the earth, the sun can only shine on one half at a time. Let, therefore, the shaded portions represent the dark, and the light portions the illuminated halves. Further, in all the different positions, let *E C* represent the ecliptic, *P e* the arctic circle, and *d m* the antarctic.

Now, when the earth is in the position marked Aries, both poles, *P m*, fall just with the illuminated half. It is, therefore, day over half the northern and half the southern hemispheres at once. And as the earth turns round on her axis, the day and night must each be of equal length—that is to say, twelve hours long—all over the globe. Of course, precisely the same holds for the position at Libra. The former corresponds to September, the latter to March.

But when the earth reaches Capricorn in June, one of her poles, *P*, will be in the illuminated half, the other, *m*, in the dark; and for a space reaching from *P* to *e*, and *m* to *d*, a certain portion of her surface will also be illuminated, or also in shadow. The illuminated space, *P e*, as the earth makes her daily rotation, will be exposed to the sun all the time; the dark space, *m d*, will be all the time in shadow. At this period of the year the sun never sets at the north polar circle, and never rises at the south. And the converse of all this happens when the earth moves round to Cancer, in December.

Why does the earth's axis always point in the same direction? Explain the phenomena of the seasons.

The temperature of any place depends on the amount of heat it receives from the sun. During the day the earth is continually warming; during the night cooling. When the sun is more than twelve hours above the horizon, and less than twelve below, the temperature rises, and conversely. When the earth moves from Libra to Capricorn, in the northern hemisphere, the days grow longer and the nights shorter, and the rise of temperature we call the approach of spring. As she passes from Capricorn to Aries, summer comes on. From Aries to Cancer, the night becomes longer than the day, and it is autumn—the reverse taking place from Cancer to Libra. It is also to be remarked, that similar but reverse phenomena are occurring for the southern hemisphere. This, therefore, accounts for the seasons, and accounts for all their attendant phenomena, that the sun never sets in the polar circles during summer, nor rises during winter.

LECTURE LXV.

THE SOLAR SYSTEM.—*The Planetary Bodies.—Inferior and Superior Planets.—Mercury.—Venus, her motions and phases.—Transits of Venus over the Sun.—Their importance.—Mars, his physical appearance.*

HAVING established the general relations of the earth and sun, and shown how the former revolves round the latter in an elliptic orbit, we proceed, in the next place, to a description of the solar system.

It has already been stated that among the stars there are some which plainly possess proper motions, sometimes being found in one part of the heavens and sometimes in another. To these, from their wandering motion, the name of planets has been given. Like the earth, they revolve in elliptic orbits round the sun. Their names, commencing with the nearest to the sun, are—

Mercury,	Juno,	Jupiter,
Venus,	Ceres,	Saturn,
Earth,	Pallas,	Uranus,
Mars,	Astrea,	Neptune.
Vesta,		

On what does the temperature of any place depend? How is this connected with the seasons? What are the planets? Mention their names.

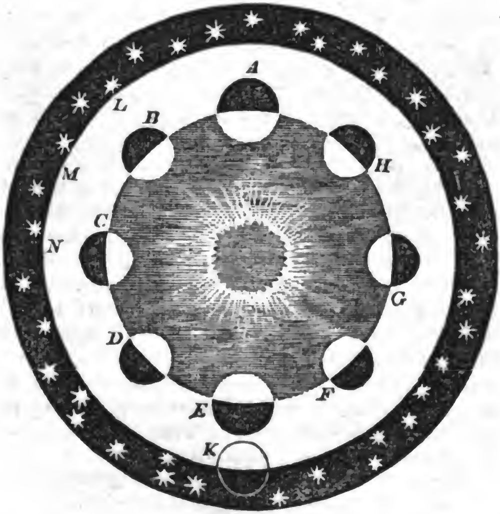
There are, therefore, two whose orbits are included in that of the earth, the others are on the outside of it.

MERCURY always appears in the close neighborhood of the sun, and hence is ordinarily difficult to be seen. In the evening, after sunset, he may, at the proper time, be discovered, but, soon retracing his path, is lost among the solar rays. After a time he reappears in the morning, and proceeding farther and farther from the sun, with a velocity continually decreasing, he finally becomes stationary, and then returns, to reappear again in the evening.

The distance of this planet from the sun is more than 37,000,000 of miles, his diameter 3200, he turns on his axis in 24h. 5′ 3″, and moves in his orbit with a velocity of 111,000 miles in an hour.

VENUS, which is the next of the planets, and, like Mercury, is inferior—that is, has her orbit interior to that of the earth—from her magnitude and position, enables us to trace the phenomena of such a planet in a clear and

Fig. 346.



Under what circumstances may Mercury be seen? What is his distance from the sun, his diameter, and the time of his rotation?

perfect manner. She, too, is seen alternately as an evening and morning star, being first discovered, as at A, *Fig.* 346, emerging from the rays of the sun, and moving with considerable rapidity from A toward B. Let K be the position of the observer on the earth, which, for the present, we will suppose to be stationary. To such an observer the motion of Venus, as she recedes from the sun, appears to become slower and slower, then to cease. And now the planet, passing from C to E, appears to have a retrograde motion, the velocity of which continually increases, then again lessens as she moves toward G, then ceases; and, lastly, the planet moves toward A with a continually accelerated motion.

All this is evidently the effect which must ensue with a body pursuing an interior orbit. The stationary appearance arises from the circumstance that at one point, C, she is coming toward the earth, at the opposite, G, retreating from it; while at A and at E she is crossing the field of view.

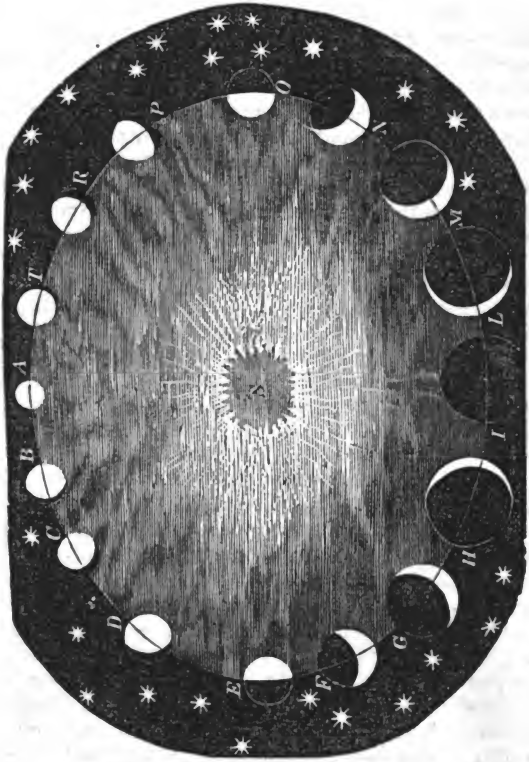
But the planets shine only by the light of the sun. Venus, moving thus in an interior orbit, ought, therefore, to exhibit phases. Thus, in *Fig.* 347, when she first emerges from the rays of the sun on the opposite side, as respects the earth, a position which is called her superior conjunction, A, she must exhibit to us the whole of her illuminated disc; but, as she passes from A to B, a portion of her unilluminated hemisphere is gradually exposed to view. This increases at D; and at E we see half of the illuminated and half of the dark hemisphere. She looks, therefore, like a little half moon. As she comes into the position F G H we see more and more of her dark side. She becomes a thinner and thinner crescent, and at I is extinguished; and, passing from this toward L M N O, and from that to A, we gradually recover sight of more and more of her illuminated disc.

These phenomena must necessarily hold for a planet moving in an interior orbit, and were predicted before the invention of the telescope. That instrument established the accuracy of the prediction.

The points E and O are the points of greatest elongation, A is the superior conjunction, and I the inferior.

What phenomena does Venus exhibit? How do we account for her direct and retrograde motions? Why does she exhibit phases?

Fig. 347.



Common observation shows that this planet differs very much at different times in brilliancy. Two causes affect her in this respect:—1st, the different amount of illuminated surface which we perceive; 2d, the difference of apparent magnitude of the planet as she changes position in her orbit. On her approach toward the earth from E to H the illuminated portion visible lessens; but then her dimensions increase by reason of her proximity. The

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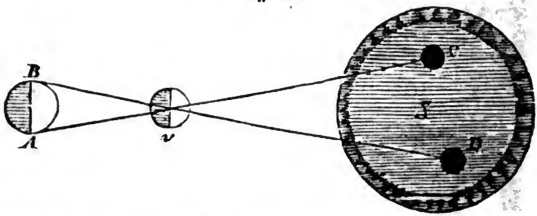
What are the points of her greatest elongation and the superior and inferior conjunction? What causes affect the brilliancy of this planet?

maximum of brilliancy takes place when she is about 40° from the sun.

Moreover, it is obvious that at certain intervals, at the time of the inferior conjunction, both this and the preceding planet must appear to cross the face of the sun. To this phenomenon the name of a transit is given. The planet then appears as a round black spot or disc projected on the sun. In the case of Venus, these transits take place at intervals of about eight and one hundred and thirteen years. They furnish the most exact means of determining the sun's parallax. Let A B, *Fig.* 348, be the earth, V Ve-

Fig. 348.



nus, S the sun. Let a transit of the planet be observed by two spectators, A B, at the opposite points of that diameter of the earth, perpendicular to the ecliptic. Then the spectator at A will see Venus projected on the sun's disc at C, and B at D; but the angle A V B is equal to the angle C V D; and since the distance of the earth from the sun is to that of Venus from the same body, as about 2½ to 1, C D will occupy on the sun's disc a space 2½ times that under which the earth's diameter is seen—that is to say, five times as much as the horizontal parallax. The sun's parallax, as determined from the transit of 1769, is 8″·6 nearly.

The period occupied by this planet in performing her revolution round the sun is 224 days, 16 hours, 42 minutes, 25.5 seconds. The orbit is inclined to the ecliptic 3° 23′ 25″. She revolves on her axis in 23h 21′ 19″. Her diameter is about 7800 miles. She is, therefore, very nearly the size of the earth.

When is she most brilliant? What is a transit? At what intervals do these take place in the case of Venus? How are these used to determine parallax? What is the period of revolution of this planet? What is her diameter?

MARS is the next planet, the earth intervening between him and Venus, his orbit is, therefore, an exterior one, and in common with the others that follow, he is designated as a superior planet. He is of a reddish color, and sometimes appears gibbous, and both when in conjunction and opposition exhibits a full disc. The diameter differs very greatly according to his position, and with it, of course, his brilliancy varies. The distance from the sun is about 146 millions of miles, he revolves on his axis in 24h 31′ 32″, the inclination of his orbit to the ecliptic is 1° 51′ 1″. As with the earth his polar diameter is shorter than his equatorial.

The physical appearance of Mars is somewhat remarkable. His polar regions, when seen through a telescope, have a brilliancy so much greater than the rest of his disc that there can be little doubt that, as with the earth so with this planet, accumulations of ice or snow take place during the winters of those regions. In 1781 the south polar spot was extremely bright; for a year it had not been exposed to the solar rays. The color of the planet most probably arises from a dense atmosphere which surrounds him, of the existence of which there is other proof depending on the appearance of stars as they approach him; they grow dim and are sometimes wholly extinguished as their rays pass through that medium.

Fig. 349.

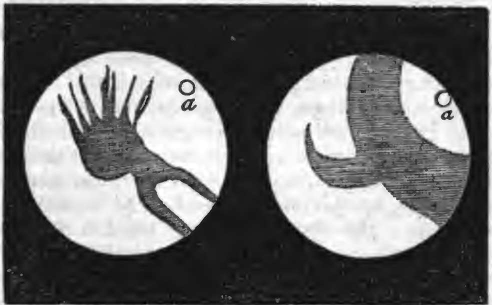


Fig. 349 represents the telescopic appearance of Mars, according to Herschel; *a* is the polar spot.

Why is Mars called a superior planet? Does he exhibit phases? What is there remarkable respecting his physical appearance? What reasons are there for supposing he has a dense atmosphere?

LECTURE LXVI.

THE SOLAR SYSTEM.—*The Five Asteroids.—Jupiter and his Satellites.—Saturn, his Rings and Satellites.—Uranus.—Neptune.—The Comets.—Returns of Halley's Comet.—Comets of Encke and Biela.*

OUTSIDE of the orbit of Mars there occur five telescopic planets closely grouped together—they are VESTA, JUNO, CERES, PALLAS, and ASTREA. They have all been discovered within the present century, the last of them in 1846. From their smallness and distance they are far from being well known. The following table contains the chief facts in relation to them.

	Period of Revolution.	Inclination of Orbit to Ecliptic.	Distance in miles.	Diameter in miles.
Vesta	3 yrs. 66 d. 4 h.	7° 8′	225.000.000	
Juno	4 yrs. 128 d.	13° 4½′	256.000.000	1320
Ceres	4½ yrs.	10° 37′ 25″	264.000.000	1320
Pallas	4 yrs. 7 m. 11 d.	34° 37′ 30″	267.000.000	1920
Astrea	4 yrs. 2 m. 4 d.	5° 20′	250 000 000	

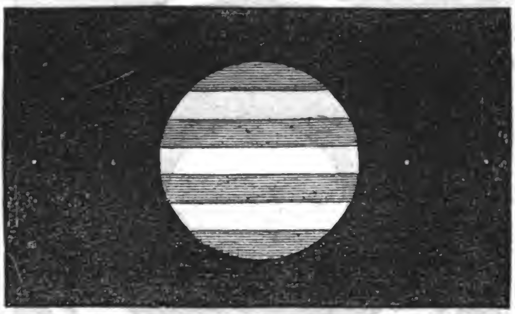
It has been thought that these small planets are merely the fragments of a much larger one which has been burst asunder by some catastrophe. There seems to be some foundation for this opinion. It has been asserted that they are not round, but present angular faces. They are also enveloped in dense atmospheres, and in the case of Juno and Pallas, their orbits are greatly inclined to the ecliptic. These planets are sometimes called asteroids.

JUPITER, the largest and perhaps the most interesting of the planets, has his orbit immediately beyond that of the asteroids. He always presents his full disc to the earth, and performs his revolution round the sun in 11 years 318 days, at a distance of 495 millions of miles. He is nearly 1500 times the size of the earth, being 89,000 miles in diameter.

What planets come next in order to Mars? What is there remarkable respecting the size and orbits of these planets? Under what name do they also go? What is the position and size of Jupiter?

Immediately after the invention of the telescope, it was discovered by Galileo that Jupiter is attended by four satellites or moons, which revolve round him in orbits almost in the plane of his equator. Each of these satellites revolves on its own axis in the same time that it goes round its primary, so that, like our own moon, they always turn the same face to the planet. Like our moon, also, they exhibit the phenomena of lunar and solar eclipses. Advantage has been taken of these

Fig. 350.



eclipses to determine terrestrial longitudes, and we have already seen it was from them that the progressive motion of light was first established.

Jupiter revolves on his axis in 9h. 56′. This rapid rotation, therefore, causes him to assume a flattened form—his polar axis being $\frac{1}{14}$ shorter than his equatorial, and as his axis is nearly perpendicular to the plane of his orbit, his days and nights must be equal, and there can be but little variation in his seasons. His disc is crossed by belts or zones, which are variable in number and parallel to his equator.

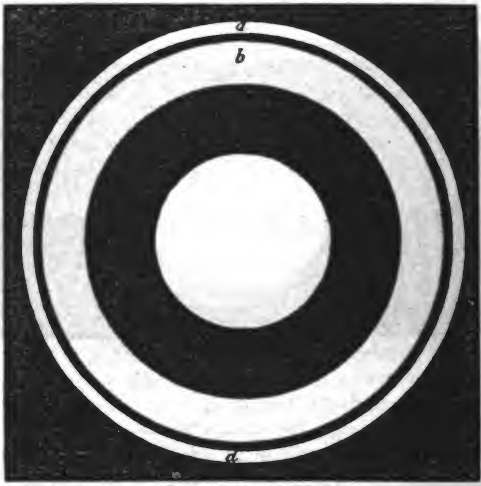
SATURN, which is the next planet, performs his revolution round the sun in about twenty-nine years and a half, at a distance of 915 millions of miles. The inclination of his orbit to the ecliptic is 2° 30′. He is about 900 times larger than the earth, being 79,000 miles in diameter.

How many satellites has he? What advantage has been taken of their eclipses? What is the time of rotation of this planet on his axis? What is the relation of his equatorial to his polar diameter? What is the distance and size of Saturn?

He turns on his axis in 10½ hours, and the flattening of his polar diameter is $\frac{1}{11}$.

Seen through the telescope, Saturn presents a most extraordinary aspect. His disc is crossed with belts, like those of Jupiter; a broad thin ring, or rather combination of rings, surrounds him, and beyond this seven satellites revolve. The ring is plainly divided into two concentric portions, *a b*, as seen in *Fig.* 351, and other sub-

Fig. 351.



divisions have been suspected. The larger ring is nearly 205,000 miles in exterior diameter, and the space between the two 2680 miles. The rings revolve on their own center—which does not exactly coincide with the center of Saturn—in about 10 hours and 20 minutes. The excentricity of the rings is essential to their stability.

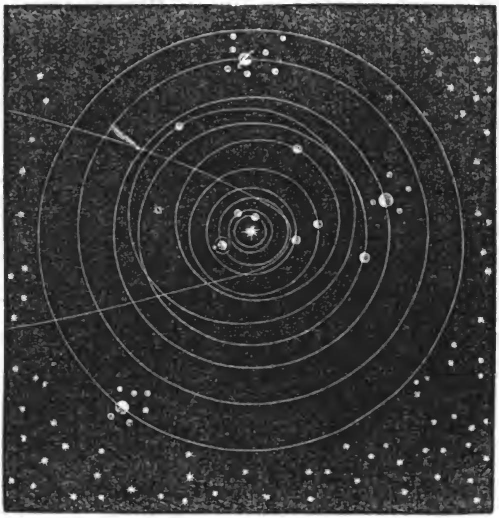
URANUS, discovered in 1781, by Herschel, revolves in an orbit exterior to Saturn, in a period of about 84 years, and at a distance of 1840 millions of miles. The inclination of its orbit to the ecliptic is 46½′. It can only be seen by the telescope. Its diameter is 35,000 miles. Six satellites have been discovered.

By what extraordinary appendage is he attended? How many satellites has he? What is the distance of Uranus? By whom was he discovered?

NEPTUNE.—This planet was discovered in 1846, in consequence of mathematical investigations made by Adams and Leverrier, with a view of explaining the perturbations of Uranus. It was also seen in 1795 by Lalande, and regarded by him as a fixed star. Its period is about 166 years—very nearly double that of Uranus. The inclination of its orbit is 1° 45′. The excentricity is only 0.005. The orbit is, therefore, more nearly a perfect circle than that of any other planet. There is reason to believe that Neptune is surrounded by a ring analogous to the ring of Saturn.

The planetary bodies now described, with their attendant satellites and the sun, taken collectively, constitute the solar system, a representation of which, as respects the order in which the bodies revolve, is given in *Fig.* 352. In the center is the sun, and in close proximity to

Fig. 352.



him revolves Mercury, outside of whose orbit comes Venus. Then follows the earth, attended by her satellite,

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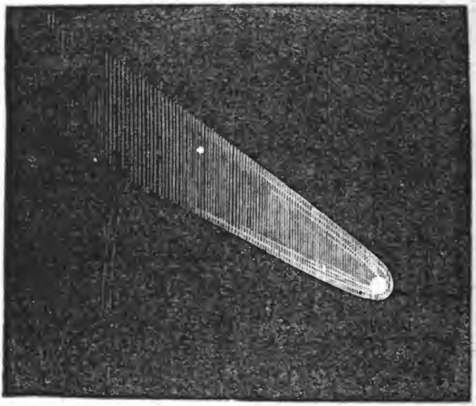
What is the position of Neptune? Of what is the solar system composed?

the moon. Beyond the earth's orbit comes Mars; then come the asteroids, followed by Jupiter, with his four moons. Still more distant is Saturn, surrounded by his rings and seven satellites; then Uranus, with six; and lastly, so far as our present knowledge extends, comes the recently-discovered planet Neptune.

Such a representation as that given in *Fig.* 352, can merely illustrate the order in which the members of the solar system occur, but can afford no suitable idea of their relative magnitudes and distances. Thus, in that figure, the apparent diameter of the sun is about the tenth of an inch, and were the proportions maintained, the diameter of the orbit of the planet Neptune should be about fifty feet. A similar observation might be made as respects the planetary masses.

But besides these bodies, there are others now to be described, which are members of our solar system. They are the comets. They move in very excentric orbits, and are only visible to us when near their perihelion. In appearance they differ very greatly from one another, but

Fig. 353.



most commonly consist of a small brilliant point, from which there extends what is designated the tail. Some-

In what respects are such representations of the solar system as that in *Fig.* 352 imperfect? What are comets? What is remarkable as respects their physical constitution?

times they are seen without this remarkable appendage. In other instances it is of the most extraordinary length, and in former ages, when the nature of these bodies was ill understood, occasioned the utmost terror, for comets were looked upon as omens of pestilence and disaster. The comet of 1811 had a tail nearly 95 millions of miles in length—that of 1744 had several, spreading forth in the form of a fan.

The history of the discovery of the nature of comets is very interesting. Dr. Halley, a friend of Sir I. Newton, had his attention first fixed on the probability that several bodies, recorded as distinct, might be the periodic returns of the same identical comet, and closely examining one which was seen in 1682, came to the conclusion that it regularly appeared at intervals of seventy-five or seventy-six years. He therefore predicted that it ought to reappear about the beginning of the year 1759. The comet actually came to its perihelion on March the 13th of that year, and again, after an interval of seventy-six years, in 1835.

Besides the comet of Halley, there are two others, the periodic returns of which have been repeatedly observed. These are the comet of Encke and that of Biela. The former is a small body which revolves in an elliptical orbit, with an inclination of $13\frac{1}{2}°$ in about 1200 days. Its nearest approach to the sun is about to the distance of the planet Mercury; its greatest departure somewhat less than the distance of Jupiter. Its motion is in the same direction as that of the planets.

The comet of Biela has a period of 2460 days. It moves in an elliptical orbit, the length of which is to the breadth as about three to two. Its nearest approach to the sun is about equal to the distance of the earth; its greatest removal somewhat beyond that of Jupiter. It reappears with great regularity, but in the month of January, 1846, it exhibited the wonderful phenomenon of a sudden division, two comets springing out of one. This fact was first seen by Lieutenant Maury, at the National Observatory at Washington.

Nothing is known with precision respecting the nature

When was the periodic return of comets first detected? What other two comets have been frequently re-observed? What remarkable result has been noticed respecting Biela's comet?

of these bodies. They are apparently only attenuated masses of gas, for it is said that through them stars of the sixth or seventh magnitude have been seen. In the case of some there appears to have been a solid nucleus of small dimensions.

LECTURE LXVII.

THE SECONDARY PLANETS OR SATELLITES.—*The Moon, her Phases, her Period of Revolution, her Physical appearance—always presents the same face.—Eclipses of the Moon.—Eclipses of the Sun.—Recurrence of Eclipses.—Occultations.*

THE motions of the secondary bodies of the solar system, the satellites, and more especially the phenomena of our own moon, deserve, from their importance, a more detailed investigation. To these, therefore, I proceed in this lecture.

That the moon has a proper motion in the heavens the observations of a single night completely proves. She is translated from west to east, so that she comes to the meridian about forty-five minutes later each day, and performs her revolution round the earth in about thirty days, exhibiting to us each night appearances that are continually changing, and known under the name of *phases.*

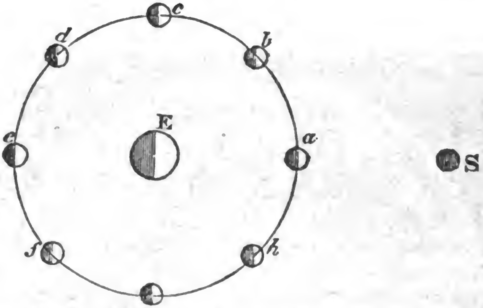
First when seen in the west, in the evening, she is a crescent, the convexity of which is turned to the sun. From night to night the illuminated portion increases, and about the seventh day she is half-moon. At this time she is said to be in her quadrature or dichotomy. The enlightened portion still increasing, she becomes gibbous, and about the fifteenth day is *full.* She now rises at sunset.

From this period she continually declines, becomes gibbous, and at the end of a week half-moon. Still further she is crescentic; and at last, after twenty-nine or thirty days, disappears in the rays of the sun.

What is supposed to be the physical constitution of these bodies? What is the direction of the moon's motion? In what time is a complete revolution completed? What are her phases? Describe their order.

At new-moon, she is said to be in *conjunction* with the sun, at full-moon in *opposition;* and these positions are called *syzygies;* the intermediate points between the syzygies and quadratures are *octants.*

Fig. 354.

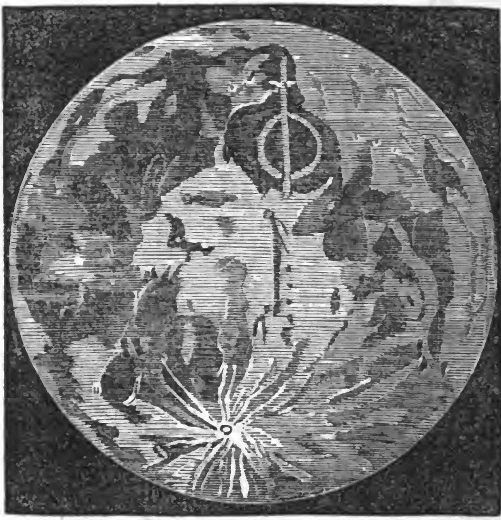


The cause of the moon's phases admits of a ready explanation on the principle that she is a dark body, reflecting the light of the sun, and moving in an orbit round the earth. Thus, let S, *Fig.* 354, be the sun, E the earth, and *a b c,* &c., the moon seen in different positions of her orbit. From her globular figure, the rays of the sun can only illuminate one half of her at a time, and necessarily that half which looks toward him. Commencing, therefore, at the position *a*, where both these bodies are on the same side of the earth, or in conjunction, the dark side of the moon is turned toward us, and she is invisible; but as she passes to the position *b*, which is the octant, the illuminated portion comes into view. And when she has reached the position *c*, her quadrature, we see half the shining and half the dark hemisphere. Here, therefore, she is half-moon. From this point she now becomes gibbous; and at *e*, being in opposition, exposes her illuminated hemisphere to us, and is, therefore, full-moon. From this point, as she returns through *f g h*, she runs through the reverse changes, being in succession gibbous, half-moon, crescentic, and finally disappearing.

What are the syzygies, and quadratures, and octants? What is the explanation of the phases?

Viewed through a telescope, the surface of the moon is very irregular, there being high mountains and deep pits upon it. These, in the various positions she assumes as respects the sun, cast their shadows, which are the dark marks we can discover by the eye, on her disc, and which are popularly supposed to be water.

Fig. 355.



The moon's diameter, measured at different times, varies considerably. This, therefore, proves that she is not always at the same distance from the earth; and, in fact, she moves in an ellipsis, the earth being in one of the foci. Her distance is about 230,000 miles. She accompanies the earth round the sun, and turns on her axis in precisely the same length of time which it takes her to perform her monthly revolution. Consequently, she always presents to us the same face. Her orbit is inclined to that of the ecliptic, at an angle of little more than five

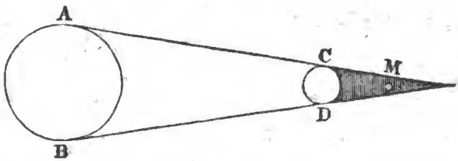
What is the appearance of the moon seen through a telescope? Is her apparent diameter always the same? What is her distance? What is her period of rotation on her axis? Does she always present exactly the same face to the earth?

degrees. Its points of intersection with the ecliptic are the nodes. Her greatest apparent diameter is 33½ minutes. The nodes move slowly round the ecliptic, in a direction contrary to that of the sun, completing an entire revolution in about eighteen years and a half. Although, for the most part, she presents the same face to the earth, as has been said, yet this, in a small degree, is departed from in consequence of her libration. This takes place both in longitude and latitude, and brings small portions of her surface, otherwise unseen, into view.

The relations of the sun, the earth, and the moon to one another afford an explanation of the interesting phenomenon of eclipses. These are of two kinds—eclipses of the moon and those of the sun.

The earth and moon being dark bodies, which only shine by reflecting the light of the sun, project shadows into space. Let, therefore, A B, *Fig.* 356, be the sun, C D the earth, and M the moon, in such a position, as respects each other, that the moon, on arriving in opposition, passes through the shadow of the earth. The light is, therefore, cut off, and a lunar eclipse takes place.

Fig. 356.



The shadow cast by the earth is of a conical form, a figure necessarily arising from the great size of the sun when compared with that of the earth. The semi-diameter of the shadow at the points where the moon may cross it varies from about 37′ to 46′—that is, it may be as much as three times the semidiameter of the moon. A lunar eclipse may, therefore, last about two hours.

The time of the occurrence of an eclipse of the moon is the same at all places at which it is visible. It is, of course visible at all places where the moon is then to be

How many kinds of eclipses are there? Under what circumstance does a lunar eclipse take place? How long may a lunar eclipse last? How is its magnitude estimated?

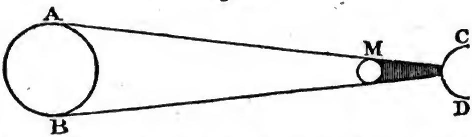
seen. The magnitude of the eclipse is estimated in digits, the diameter of the moon being supposed to be divided into twelve digits.

Whatever may be the circumstances under which a lunar eclipse takes place, the shadow of the earth is always circular. Advantage has already been taken of this fact in giving proof of the spherical figure of the earth.

If the plane of the moon's orbit were not inclined to the ecliptic there would be a lunar eclipse every full moon. It is necessary, therefore, for this to occur, that the moon should be either in or near to the node, so that the sun, the earth, and the moon may be in the same line. It was explained in Lecture XXXV., that a body situated under the same circumstances as those under which the earth is now considered forms a *penumbra* as well as a true shadow. There is, therefore a gradual obscuration of light as the moon approaches the conical shadow, arising from its gradual passage through the penumbra.

An eclipse of the sun takes place under the following circumstances. Let A B, *Fig.* 357, be the sun, M the moon, and C D the earth. Whenever the moon passes

Fig. 357.



directly between the earth and the sun, she hides his disc from us, and a solar eclipse takes place. It is partial when only a portion of the sun is obscured, annular when a ring of light surrounds the moon at the middle of the eclipse, and total when the whole sun is covered.

As the moon is so much smaller than the earth, the conical shadow which she casts can only cover a portion of the earth at a time. Solar eclipses occur at different times to different observers, and in this respect, therefore, eclipses of the moon are more frequently observed than

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What is to be observed respecting the figure of the earth's shadow? Why is there not a lunar eclipse every month? Under what circumstance does an eclipse of the sun take place? Why is there a difference between solar and lunar eclipses as respects the time at which they are seen, and also as respects their relative frequency?

those of the sun. Like lunar eclipses, solar ones can only occur in or near one of the nodes. Solar eclipses can only occur at new moon, and lunar at full moon.

Like the earth, the moon casts a penumbra; it is a cone, the axis of which is a line joining the centers of the moon and sun, and the vertex of which is a point where the tangents to the opposite sides of the bodies intersect.

Eclipses recur again after a period of about 18½ years. In each year there cannot be less than two nor more than seven eclipses; in the former case they are both solar, in the latter there must be five of the sun and two of the moon. There must, therefore, be at least two eclipses of the sun each year, and cannot be more than three of the moon.

The satellites which move round Jupiter, Saturn, and Uranus, exhibit the same phenomena of phases and eclipses to the inhabitants of those bodies as are exhibited to us by our moon. Advantage has been taken of the eclipses of Jupiter's satellites for the purpose of determining longitudes upon the earth, and from them the progressive motion of light was first established.

An *occultation* is the intervention of the moon between the observer and a fixed star. Occultations may be used for the determination of longitudes.

After what period do eclipses recur? How may they occur as to number each year? What use is made of the eclipses of Jupiter's satellites? What is an occultation?

LECTURE LXVIII.

THE FIXED STARS.—*Apparent Magnitudes.—Constellations.—The Zodiac.—Nomenclature of the Stars.—Double Stars.—Parallax.—Distance of the Stars.—Groups of Stars.—Nebulæ.—Constitution of the Universe.—Nebular Hypothesis.*

WITH the exception of the sun and moon, the heavenly bodies hitherto described form but an insignificant portion of the display which the skies present to us. For, besides them there are numberless other bodies of various sizes which, for very great periods of time, maintain stationary positions, and for this reason are designated as fixed stars.

The fixed stars are classed according to their apparent dimensions; those of the first magnitude are the largest, and the others follow in succession; the number increases very greatly as the magnitudes are less. Of stars of the first magnitude there are about eighteen, of those of the second sixty, and the telescope brings into view tens of thousands otherwise wholly invisible to the human eye.

From very early times, with a view of the more ready designation of the stars, they have been divided into constellations; that is, grouped together under some imaginary form. The number of these for both hemispheres exceeds one hundred. They are commonly depicted upon celestial globes.

The ecliptic passes through twelve of the constellations, occupying a zone of sixteen degrees in breadth, through the middle of which the line passes. This zone is called the zodiac, and its constellations with their signs are as follows:

Aries	♈	Libra	♎
Taurus	♉	Scorpio	♏
Gemini	♊	Sagittarius	♐
Cancer	♋	Capricornus	♑
Leo	♌	Aquarius	♒
Virgo	♍	Pisces	♓

What are the fixed stars? How are they divided? How many of the first and second magnitudes are there? What are constellations? What is the zodiac? Mention the constellations of it.

The order in which they are here set down is the order which they occupy in the heavens, commencing with the west and going east. Motions of the sun and planets in that direction are, therefore, said to be direct, and in the opposite retrograde.

To many of the larger stars proper names have been given. These, in many instances, are oriental, such as Aldebaran, but they are chiefly designated by the aid of the Greek letters, the largest star in any constellation being called α, the second β, &c., to these letters the name of the constellation is annexed.

The position of any star is determined by its declination and right ascension, and though these positions are commonly regarded as fixed, yet the great perfection to which modern astronomy has arrived has shown that the stars are affected by a variety of small motions, although, in some instances, these may arise in extrinsic causes, such, for example, as in the case of aberration, yet there can now be no doubt that the stars have proper motions of their own. This is most satisfactorily seen in the case of double stars, of which there are several thousands. These are bodies commonly arranged in pairs close together, the physical connection between them is established by the circumstance that they revolve round one another; thus, γ, Virginis, has a period of 629 years, and ε, Bootis, one of 1600 years.

From the planets the stars differ in a most striking particular: they shine by their own light. It this respect they resemble our sun, who must himself, at a suitable distance, exhibit all the aspect of a fixed star. We therefore infer that the stars are suns like our own, each, probably like ours, surrounded by its attendant but invisible planets; and, therefore, though the number of the stars as seen by telescopes may be countless, the number of heavenly bodies actually existing, but not apparent because they do not shine by their own light, must be vastly greater. In our solar system there are between thirty and forty opaque globes to one central sun.

It is immaterial from what part of the earth the fixed

What are direct and what retrograde motions? How are stars designated? How is their position determined? How is it known that some of them have proper motions? What are double stars? In what respect do stars differ from planets?

stars are seen; they exhibit no change of position, and have no horizontal parallax: an object 8000 miles in diameter, at that distance is wholly invisible from them. But more, when viewed at intervals of six months, when the earth is on opposite sides of her orbit—a distance of 190 millions of miles intervening—the same result holds good. To the nearest of them, therefore, our sun must appear as a mere mathematical lucid point—that is to say, a star.

In Lecture LXV., the method of determining the distance of the sun has been given. The same principles apply in the determination of the distance of a fixed star. The horizontal parallax may be found without difficulty for the bodies of our solar system: it is, in reality, the angle under which the earth's semi-diameter is seen from them. But when this method is applied to the fixed stars, it is discovered that they have no such sensible parallax; and, therefore, that the earth is, as has been observed, wholly invisible from them. This is illustrated in *Fig*. 358, in which let S be the sun, A B C D the earth, moving in her orbit, and the lines A *a*, B *b*, C *c*, D *d* the axis of the earth, continued to the starry heavens. This axis, we have seen in Lecture XXI., is always parallel to itself; it would therefore trace in the starry heavens a circle, *a b c d*, of equal magnitude with the earth's orbit, A B C D—that is, 190 millions of miles in diameter. If H be a star, when the earth is at the point A of her orbit the star will be distant from the pole of the heavens by the distance *a* H, and when she is at the point C, by the distance *c* H. It takes the earth six months to pass from A to C, 190 millions of miles. But the most delicate means have hitherto failed to detect any displacement of a star, such as H, as respects the pole, when thus examined semi-annually. It follows, therefore, that the diameter of the earth's orbit is wholly invisible at those distances.

Again, let E F I G, *Fig*. 359, represent the orbit of the earth, and K any fixed star, it is obvious that when the earth is at G the star would be seen by G K, and referred to the point, *i*; when the earth is at F it would be seen by F K, and referred to *h*, and the angle *i* K *h*, which

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Have the stars any diurnal parallax? What must be the appearance of our sun to them? Explain the illustrations given in *Figs*. 358 and 359 respecting parallax.

Fig. 358.

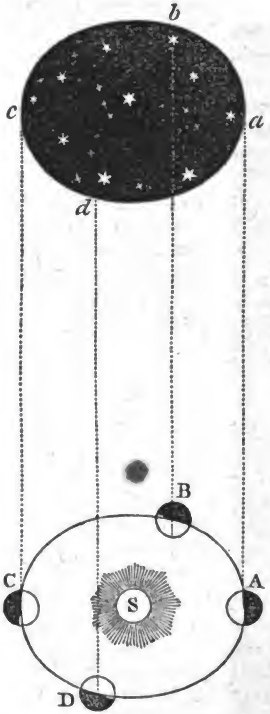
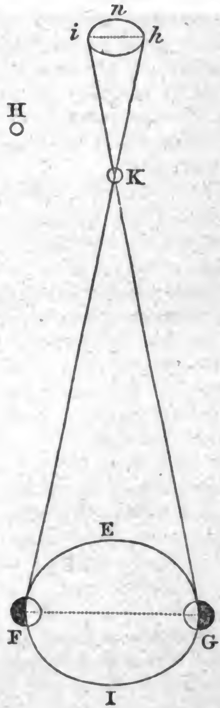


Fig. 359.



is equal to F K G, would be the *annual parallax*, or the angle under which the earth's orbit would be seen from the star. But though this is 190 millions of miles, so immense is the distance at which the fixed stars are placed that it is wholly imperceptible.

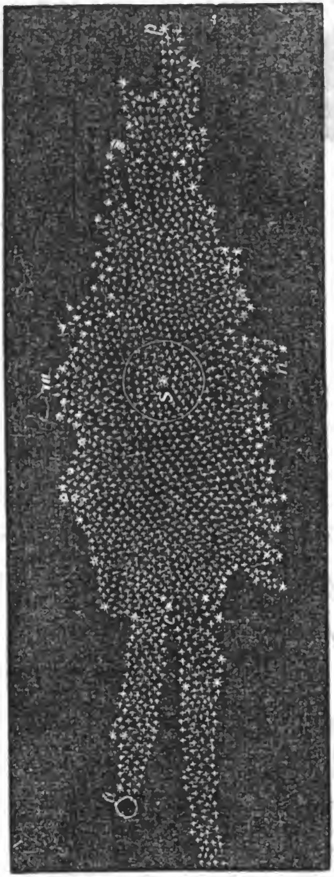
In a few instances, however, an annual parallax has been discovered. Thus, in the star 61 Cygni, amounts to about one third of a second. The distance of the nearest fixed star is, therefore, enormously great.

The stars are not scattered uniformly over the vault of

Have any stars an annual parallax?

heaven, but appear arranged in collections or groups.

Fig. 360.



Just as the planets and their satellites make up, with our sun, one little system, so too do suns grouped together form colonies of stars. The milky way, *Fig*. 360, which is the group to which we belong, consists of myriads of such suns, bound together by mutual attractive influences. In this *S* may represent the position of the solar system, and the stars will appear more densely scattered when viewed along *S p*, than along *S m*, *S n*, *S c*. But in other portions of the heavens are discovered small shining spaces—*nebulæ*, as they are called—which, under powerful telescopes, are resolved into myriads of stars, *Fig*. 361, so far off that the human eye, when unassisted, is wholly unable to individualize them, and catches only the faint gleam of their collected lights. Of these great numbers are now known.

Such, therefore, is the system of the world. A planet, like Jupiter, with his attendant moons, is, as it were, the point of commencement; a collection of such opaque bodies playing round a central sun is a further advance—a system of suns, such as form the more

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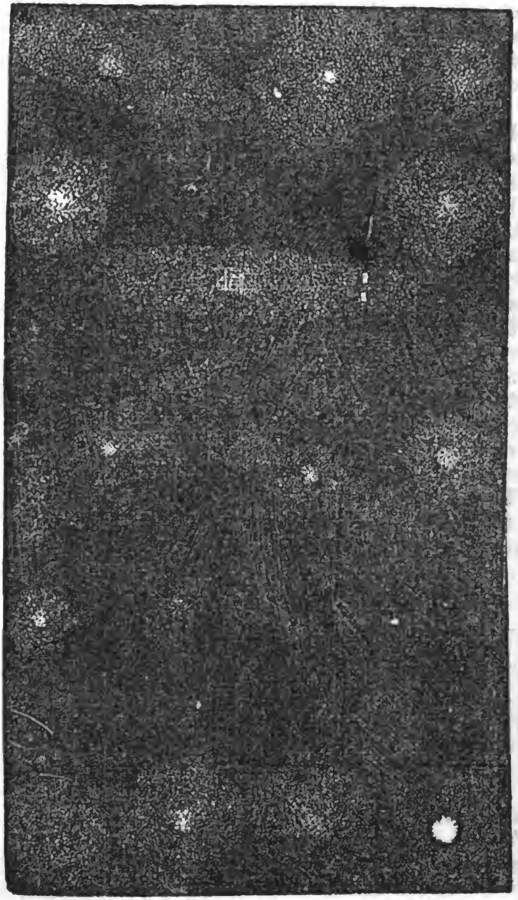
What are nebulæ? What is the milky way?

Fig. 361.

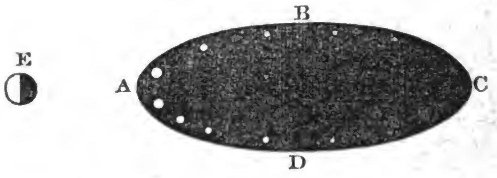


brilliant objects of our starry heavens—and thousands of such nebulæ which cover the skies in whatever direction we look. These, taken altogether, constitute the UNIVERSE—a magnificent monument of the greatness of God, and an enduring memento of the absolute insignificance of man.

But though the universe is the type of Immensity and Eternity, we are not to suppose that it is wholly unchangeable. From time to time new stars have suddenly blazed forth in the sky, and after obtaining wonderful brilliancy have died away—and also old stars have disappeared. Recent discoveries have shown that the light of very many is periodic—that it passes through a cycle of change and becomes alternately more and less bright in a fixed period of days. These intervals differ in different cases, and probably all are affected in the same way. There is abundant geological evidence to show that the light and heat of our sun were once far greater than now—the luxuriant vegetation of the secondary period could only have arisen in a greater brilliancy of that orb. The sun, then, is one of these periodic stars.

The alternate appearance and disappearance of some of the new stars may arise from their orbitual motion. Thus, suppose E the earth, and A B C D the orbit of such

Fig. 362.



a star. If the major axis of this orbit be nearly in the direction of the eye, as the star approaches to A, it will rapidly increase in brilliancy, and perhaps become wholly invisible at the distant point C. Such a star should, there-

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What is the structure of the Universe? What changes have been observed in the light of some stars? Is there reason to believe that the sun is a periodic star? Explain the probable cause of the phenomena of new stars.

fore, be periodical; and that this is the case there is reason to believe as respects one which appeared in the years 945, 1264, 1572, in the constellation of Cassiopeia. Its period seems to be 319 years.

Among the nebulæ there are some which powerful telescopes fail to resolve into stars—a circumstance which has caused some astronomers to suppose that they are in reality diffused masses of matter which have not as yet taken on the definite form of globes, but are in the act of doing so. And, extending these views to all systems, they have supposed that all the planetary and stellar bodies are condensations of nebular matter. To this hypothesis, although if admitted it will account for a great many phenomena not otherwise readily explained, there are many objections: and it is also to be observed that every improvement which has been made in the telescope has succeeded in resolving into stars nebulæ until then supposed to be unresolvable. The inference, therefore, is, that were our instruments sufficiently powerful all would display the same constitution.

LECTURE LXIX.

CAUSES OF THE PHENOMENA OF THE SOLAR SYSTEM.—*Definitions of the Parts of an Elliptic Orbit.—Laws of Kepler.—Conjoint Effects of a Centripetal and Projectile Force.—Newton's Theory of the Planetary Motions.—His Deductions from Kepler's Laws.—Causes of Perturbations.*

HAVING, in the preceding Lectures, described the constitution of the solar system, and of the Universe generally, we proceed, in the next place, to a determination of the causes which give rise to the planetary movements. We have to call to mind that observation proves that the figure of the orbits of these bodies is an ellipse, the sun

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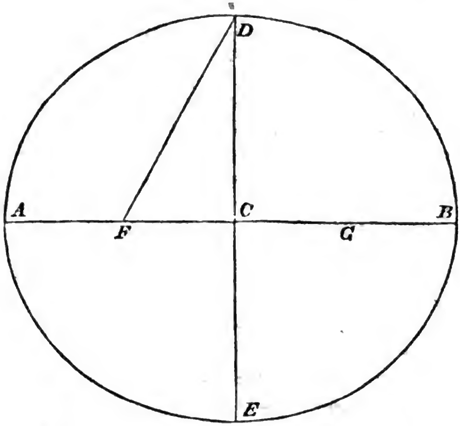
What is meant by the nebular hypothesis? What are the objections to it? Describe the parts of an elliptic orbit.

being in one of the foci. Thus, in *Fig.* 363, let *F* be the sun, *A B D E* an elliptic orbit, *A* is the perihelion, *B* the

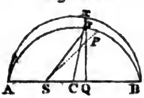
Fig. 363.



aphelion, *F D* the mean distance, and *F C*, which is the distance of the focus from the center, the excentricity; a line joining the sun and the planet is called the radius vector.

There are three anomalies—the true, the mean, and the excentric. They indicate the angular distance of a planet from its perihelion, as seen from the sun. Let A p B be the orbit of a planet, S the sun, A B the transverse diameter of the orbit, p the place of the planet, C the center of the orbit, with which center let there be described a circle, A x B; through p draw x p Q, and suppose that while the real planet moves from A to p, with a velocity which varies with its distance, an imaginary one moves in the same orbit with an equable motion, so that when the real planet is at p, the imaginary one is at P, both performing their entire revolution in the same time. Then A S p is the true anomaly, A S P the mean anomaly, A C x the excentric anomaly.

Fig. 364.



From an attentive study of the phenomena of planetary

What is the radius vector? What are the true, the mean, and the excentric anomaly?

motions, Kepler deduced their laws. These pass under the designation of the three laws of Kepler. They are—

1st. The planets all move in ellipses, of which the sun occupies one of the foci.

2d. The motion is more rapid the nearer the planet is to the sun, so that the radius vector always sweeps over equal areas in equal times.

3d. The squares of the times of revolution are to each other as the cubes of the major axes of the orbits.

It is one of the fundamental propositions of mechanical philosophy that a body must forever pursue its motion in a straight line unless acted upon by disturbing causes, and any deflection from a rectilinear course is the evidence of the presence of a disturbing force. Thus, when a stone is thrown upward in the air, it ought, upon these principles, to pursue a straight course, its velocity never changing; but universal observation assures us that from the very first moment its velocity continually diminishes, and after a time wholly ceases—that then motion takes place in the opposite direction, and the stone falls to the surface of the earth. In former Lectures, we have already traced the circumstances of these motions, and referred them to an attractive force common to all matter, and to which we give, in these cases, the name of universal attraction, or attraction of gravitation.

In speaking of the motions of projectiles, Lecture XX, it has been shown that, under the action of a force of impulse and a continuous force acting together, not only may a moving body be made to ascend and descend in a vertical line, but also in curvilinear orbits, such as the parabolic, the concavity of the curve looking toward the earth's center, which is the center of attraction. It should not, therefore, surprise us that the moon, which may be regarded in the light of a projectile, situated at a great distance from the earth, should pursue a curvilinear path, constantly returning upon itself, since such must be the inevitable consequence of a due apportionment of the intensity of the projectile and central forces to one another.

It is the force of gravity which, at each instant, makes

What are the three laws of Kepler? How may it be proved that an attractive force exists in all the planetary masses? What is the result of the action of a momentary and a continuous force?

a cannon-ball descend a little way from its rectilinear path. And it is the same force which also brings down the moon from the rectilinear path she would otherwise pursue, and makes her fall a little way to the earth. In Lecture XXI, *Fig.* 107, we have shown how, under this double influence, a circle, an ellipse, or other conic section, must be described; and it was the discovery of these things that has given so great an eminence to Sir Isaac Newton, he having first proved that it is the same force which compels a projectile to return to the earth and retains the moon in her orbit.

But more than this, extending this conclusion to the solar system generally, he showed that, as the moon is retained in her orbit by the attractive influence of the earth, so is the earth retained in hers by the attractive influence of the sun. And taking the laws of Kepler as facts established by observation, he proved, from the equable description of areas by the radius vector, that the force acting on the planets and retaining them in their orbits must be directed to the center of the sun. From Kepler's first law of the description of elliptic orbits with the sun in one of the foci, he deduced the law of gravitation or of central attraction generally—that is, that the force of attraction on any planetary body is inversely proportional to the square of its distance from the sun. And from Kepler's third law that the squares of the times of revolution are as the cubes of the major axes, he proved that the force of attraction is proportionate to the masses.

The progress of knowledge from the time of Newton until now has only served to establish the truth of these great discoveries, and far from restricting them to our own solar system, has shown beyond doubt that they apply throughout the universe. The revolutions of the double stars round one another are consequences of the same laws which determine the orbitual movements of the satellites of Jupiter round their primary, or of Jupiter himself round the sun.

Even those outstanding facts which, at an earlier period, seemed to lend a certain degree of weight against

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How may this reasoning be applied to the moon? How to the solar system generally? What did Newton deduce from Kepler's laws? Does the same theory apply beyond the solar system?

the full operation of the theory of Newton have, one after another, become illustrations of its truth as they have in succession become better understood.

Thus, for example, the deviations which the moon exhibits from a truly elliptic orbit in her passage round the earth, and which at first sight might seem to bear against Newton's theory, are, when properly considered, the inevitable consequences of it. If the motions of the moon were determined by the influence of the earth's attraction only, her orbit must be a perfect ellipse, always in the same plane, and without any retrogradation of the nodes. But observation shows that this is not the case; and, in reality, Newton's theory could have predicted what is actually the fact; for the moon is not alone under the influence of the earth, but, like the earth, simultaneously under the influence of the sun. In her monthly revolution her distance alternately varies from the latter body by nearly half a million of miles, in her opposition being farther off, and in her conjunction being nearer to him. The law of the inverse squares, therefore, comes to apply; and the result must be in some positions an acceleration, and in some a retardation of her motion. And, as her orbit is not coincident with the plane of the ecliptic, the action of the sun must necessarily tend to draw her out of that plane, and thus produce the retrograde revolution of her nodes.

The summation of the theory of Newton, therefore, comes to this, that all masses of matter in the universe attract one another with forces, the intensities of which, at equal distances, are proportional to their masses, and which, with equal masses, at different distances, are inversely proportional to the squares of those distances. That the elliptical motion results from a primitive projectile impulse impressed on the heavenly bodies by the Creator, conjoined with the continuous agency of the attractive force. Upon these principles every variety of motion exhibited by the celestial bodies may be expounded, whether it be the almost circular path described by

What should the moon's motion be if under the influence of the earth alone? What is it in reality? To what cause is this due? How is it that the sun impresses changes of velocity on the moon's motion, and makes her nodes retrograde? What are the principal points in Newton's theory?

the moon round the earth, the excessively eccentric ellipses described by some comets round the sun, or the parabolic or hyperbolic orbits followed by others; in which case they enter our system but once, and, having passed their perihelion, leave it forever. Moreover, these principles yield us a clear explanation of other facts—at first not apparently connected with them—such as perturbations generally, the figure of the earth, and the tides, which are caused in the sea by the conjoint influence of the sun and the moon, as we shall now proceed to explain.

LECTURE LXX.

THE TIDES.—*Flood and Ebb-Tide.—Spring and Neap-Tide.—General Phenomena of the Tides.—Connection with the Position of the Moon.—Effects of the Diurnal Rotation.—Action of the Sun.—Local Tidal Effects.*

BY the tide we mean an elevation and depression of the waters of the sea, occurring twice during the course of a day. For about six hours the sea flows from south to north; it then remains stationary for about a quarter of an hour, then ebbs in the opposite direction for about six hours, is then stationary again for a quarter, and then recommences to flow. To this elevation and depression the names of flood and ebb are given. And as the absolute height of the tides varies, as we shall presently see, at different times, the highest tide is called a spring-tide, and the lowest a neap-tide.

The space of time occupied in one flow and ebb is about twelve hours and twenty-five minutes. There are, therefore, two tides during one lunar day—or, what is the same, every time the moon crosses the meridian, whether superior or inferior, there is a tide; but the actual time of high water out at sea is not at the instant when the the moon is upon the meridian, but about two hours later.

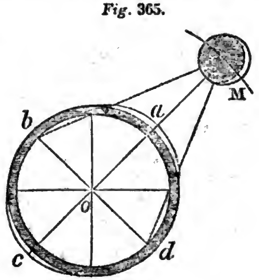
Mention some other phenomena which this theory explains. What is meant by the tide? Describe the principal phenomena of it. What is a spring and what a neap-tide? What time is occupied in one ebb and flow? What is the position of the moon at the time of high water?

There can be no doubt that it is the influence of this luminary that is the cause of the tides. Her attraction must necessarily render those portions of the sea that are immediately beneath her of less weight, and, by the laws of hydrostatics, they, therefore, must rise until an equilibrium be established. But on those points which are in quadrature with her, the effect of her action, by reason of its obliquity, is to render them heavier; and, as respects those which are diametrically opposite to her, on the other side of the earth, she must exert on them a less powerful attraction than she does on the earth's center, because they are more remote than it. From this inequality and obliquity of the moon's action there must necessarily ensue an elevation on those parts of the sea which are immediately beneath her, and also on those which are on the opposite side of the earth; but on those positions which are situated at right angles to these points there must be a depression.

When these considerations are combined with the fact of the diurnal rotation of the earth on its axis it will be perceived that the tide thus formed must necessarily follow the apparent course of the moon, and that in any given locality there must be high water and low water twice in every lunar day.

In *Fig.* 365, let *a b c d* be the earth and M the moon; and let the shaded line surrounding the earth on all sides represent its surface as covered with a uniform sea. Now, as the attractive force of the moon varies inversely as the squares of the distance, it must be strongest at *a*, more feeble at *b* and *d*, and still more feeble at *c*. Under this attractive influence the waters at *a* will necessarily rise, and the sea, losing its perfectly spherical shape, will assume that of an

Fig. 365.



To what cause is the elevation of the water due? What is the moon's action on those parts of the earth nearest and most distant from her? What on those parts at quadrature with them? Why does the tide follow the apparent course of the moon? Describe the illustration given in *Fig.* 365.

ellipsoid—or, in other words, a tide will form upon it. And, as the center of the earth at *o* is more attracted than the point *c*, because it is nearer the moon, it will advance toward the moon more than will the water at *c*; and at that point an elevation forms, so that at *a* and at *c* there will be high water. But as respects the points *b* and *d*, which are at the quadratures, the force of the moon, by reason of the obliquity under which it is acting, may there be decomposed; and if this be done it will be seen that a part of that force is expended in increasing the weight of particles in those positions—or, in other words, making them tend more powerfully toward the center of the earth. Under these circumstances, therefore, there being a diminished weight at *a* and *c*, and an increased one at *b* and *d*, the spherical form of the shell of water is lost; there is an elevation at *a* and *c* and a depression at *b* and *d*, high water at the former and low water at the latter places. And as the earth rotates on her axis so as to bring the moon upon the meridian in about twenty-four hours and fifty minutes, in that space of time there must be two tides. Were it not for this diurnal rotation there would only be two sets of tides in a month.

As a movement communicated to the waters cannot cease at once, and as the elevation of the water is moved away from the moon by the earth's revolution, the water still continues to rise for a certain time, although the point of elevation is no longer immediately beneath the moon. So the time of high water is not coincident with the passage of the moon over the meridian, but occurs somewhat later.

In the same way that the moon thus produces tides in the sea, so, too, must the sun. And, as his attractive force is much greater than hers, it might, at first sight, appear that he should give rise to far higher tides. But his great distance makes a wide difference in the result; so that, in point of fact, the moon is almost three times as energetic as he is. We have shown, in *Fig.* 365, how much the obliquity of the moon's action on the points in quadrature has to do with the final effect. Not so with the sun. His influence on the different parts of the sea

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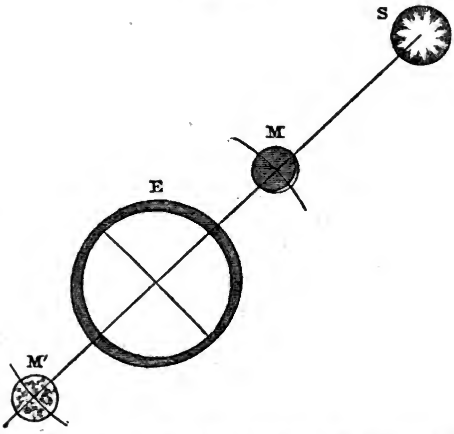
Why is not the time of high water coincident with the moon's meridian passage? Does the sun act in the same manner as the moon? What difference is there between him and the moon as respects obliquity of action?

takes place almost in parallel lines, and, therefore, the effect becomes feeble. Still the sun does each day produce two tides as the earth revolves, though they are tides of much less magnitude than the lunar ones.

In *Fig*. 366 let E be the earth, M the moon, and S the

Fig. 366.



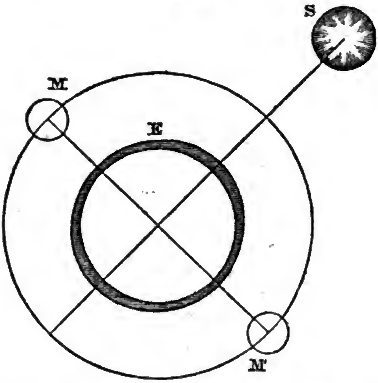
sun; and, as before, let the shaded line round the earth represent a uniform sea. Now, it is obvious that when these bodies are in the position represented in the figure the action of both will coincide, and they will jointly raise a higher tide. Also the same must take place when the sun being at S the moon is at M′. But these positions are evidently those of the new and the full moon, and therefore at these times the highest tides—spring-tides—occur.

In this case the time of the greatest elevation of water does not coincide with that of the passage of both luminaries over the meridian, but occurs some time later. A certain period is required in order to communicate motion to the mass of the water.

From what does this arise? How many solar tides are there in a day? Describe the illustration given in *Fig*. 366. At what times do spring-tides consequently occur? Does the time of greatest elevation coincide with that of the passage of both luminaries over the meridian?

Now, let the luminaries be as is represented in *Fig.* 367, where S is the sun, E the earth, surrounded by its ocean, and M or M′ the moon in either of the quadra-

Fig. 367



tures. In this position the effect of one of the bodies counteracts that of the other. Those points which in the solar tide would be high water are low water for the lunar tide. Under these circumstances the sea departs much less from its undisturbed position, and the tidal movements are less. This condition of things corresponds to the neap-tides. Neap-tides, therefore, occur when the moon is in her quadratures.

The actual rise of the tide differs very much in different places, being greatly determined by local circumstances. Thus, in the bay of Fundy it sometimes rises as high as eighty feet; in the West Indies it is said to be scarcely more than from ten to fifteen inches. These modifications arise from a great variety of disturbing causes, such as the interference of successive tide-waves, the configuration of coasts, the prevalence of winds, &c. In inland seas and lakes there are no tides, because the moon acts equally over all their surface.

How is it that neap-tides occur? What local circumstances affect the tides.

LECTURE LXXI.

THE FIGURE AND MOTIONS OF THE EARTH.—*Astronomical Appearances connected with the Earth's Figure.—Determination of the Length of a Degree.—Actual Dimensions of the Earth.—Amount of Oblateness.—Diurnal Rotation proved by the Oblateness.—Annual Motion Round the Sun proved from Aberration of the Stars.—Determination of Latitudes.—Determination of Longitudes.*

FROM considerations connected with the appearance of objects at sea, or where there is an unobstructed view of the horizon, we have already deduced the fact of the globular figure of the earth. If any doubt remained on this point it would be entirely removed by the well known circumstance that, on very many occasions, navigators have sailed round the world.

An observer situated near the equator sees the north polar star upon the horizon, but as he travels toward our latitudes the star seems to rise correspondingly in the sky, and if he could pursue his journey far enough would finally be over his head. In this fact we have another proof of the spherical figure of the earth; for, were it a flattened surface or a plane, such a change in the position of the stars could not take place.

Seeing, therefore, that our earth is of a spherical figure, it may easily be demonstrated that for every degree that we go northward upon its surface, the north pole is elevated a degree above the horizon. This observation furnishes us with a ready means of determining the actual magnitude of our planet.

For this purpose it would be only necessary to select two positions on the same meridian, at which there was a difference in the elevation of the pole of one degree; the distance between those places, if measured, would be $\frac{1}{360}$ part of the entire circumference of the earth. The problem of determining the dimensions of the earth re-

What simple facts afford proof of the globular figure of the earth? On what principle may we determine its magnitude?

solves itself, therefore, into the measurement of the length of a degree.

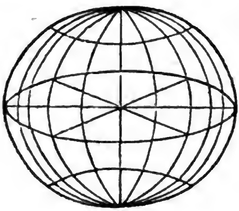
Measurements effected on these principles give for the circumference of the earth 24,880 miles, from which we deduce its diameter to be 7920.

But such measurements have also proved that the value of a degree is not the same in all places; for, as we leave the equator and go toward the poles, the length of the degree becomes greater. This, therefore, shows that though the general figure of the earth is spherical, yet it is not a perfect sphere: a perfect sphere must have its degrees of uniform length; and such an increase in the length of the degree can be explained on one principle only—that the earth is flattened toward the poles.

The analogies of other bodies in the solar system illustrate this explanation: both the great planets, Jupiter and Saturn, are flattened toward the poles, the former having his polar diameter shorter than his equatorial $\frac{1}{14}$, and the latter $\frac{1}{11}$. Such an oblate spheroidal figure is presented to us in the case of an orange. This flattening is seen in *Fig.* 368, where N S is the polar diameter. From trigonometrical measurements of the surface of the earth, it is inferred that the flattening is about $\frac{1}{300}$, or that the polar is shorter than the equatorial diameter by about twenty-six miles. The earth may be regarded, therefore, as having a zone or projecting ring upon its surface, which has a maximum thickness immediately under the equator. From the effect of gravity varying as the inverse square of the distance from the earth's center, and from the figure of the earth, its polar regions being nearer the center than its equatorial, the weight of bodies must change as we pass from the equator to the poles. Now, the number of vibrations which a pendulum of given

Fig. 368.

N



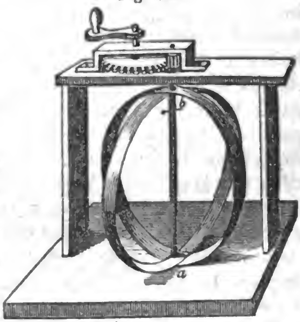
S

What are the circumference and diameter of the earth in miles? Is the length of the degree the same in all places? What follows from this as respects the earth's figure? Is this conclusion verified in the case of other planets? By how much does the equatorial exceed the polar diameter?

length makes in a given time depends on the intensity of gravity; and when one of these instruments is examined, it is found to beat more rapidly as it approaches the poles. This phenomenon has already been discussed in Lecture XXV, and referred to its proper cause. From the oscillations of a pendulum the figure of the earth may be determined.

From a variety of facts, as well as from the general analogy of every body in the solar system, the sun himself not excepted, we have deduced the fact of the daily revolution of the earth on her own axis. It is the property of all true philosophical theories to meet with confirmation under circumstances where we might have been little likely to have expected it. And so, with the diurnal revolution of the earth, it might be demonstrated from the oblate spheroidal figure, had we no other proof of it; but having such proofs in abundance, this comes as a corroborative illustration; for, as the earth revolves on her axis, it must needs follow that she, like all other revolving bodies, gives rise to a centrifugal force which is as the square of the velocity of rotation. At the equator where the speed of rotation is the greatest, and a given point passes through 25,000 miles in 24 hours—that is, with more than the speed of a cannon-ball—the centrifugal force is at a maximum, and from this point it declines until at the poles it ceases. Let us call to mind the experiment formerly exhibited by the machine represented in *Figure* 369, in which the two brass hoops, *a b*, bent into a circular form when they are made to revolve rapidly by turning the handle of the multiplying-wheel, depart from their circular shape and bulge out into that of an ellipse; and according as the velocity of rotation is greater so is the elliptical figure better mark-

Fig. 369.



How does this affect the weight of bodies and the beating of pendulums? How does the figure of the earth prove the fact of its diurnal rotation? What is the relation of the centrifugal force at the equator and at the poles?

ed. It is then the diurnal revolution of the earth on her axis which has given her a shape flattened at the poles, and in the same way in the case of all the other great planets, the flattening is immediately dependent on the velocity of rotation.

We have already given so many proofs of the earth's orbitual motion round the sun, that any thing further might seem unnecessary. I shall, however, explain what is meant by the aberration of the fixed stars, not only from its intimate connection with one of the fundamental facts in optical science—the progressive motion of light—but also from its being a striking exemplification of the truth here more immediately under consideration, the translatory movement of the earth round the sun.

Let A B C D, *Fig.* 370, be the earth's orbit, and E any given star. When the earth is at A, the star will be seen in the line A E, and referred on the sphere of the heavens to G. When the earth has passed through one half of her orbit, and arrived at C, the star will be seen in the line C E, and referred to F. From what has already been said in relation to parallax, it will be understood that this shifting of the star from G to F depends on its having a measurable distance from the earth.

With a view of determining the parallax of one of the stars, and consequently its distance from the earth, two astronomers during the last century commenced observations founded on these principles; and selecting the star γ in the constellation Draco, examined its position for the several months in the year. Thus, for example, the earth being at C in the month of September, and the star referred to F: six months afterward—that is in March—the earth being at A, they expected the star would change its position, and be referred to G; but, to their surprise, they found the movement was in precisely the opposite direction, the star being seen at K, the movement being from F to K, instead of from F to G. This is what is known as "the aberration of the fixed stars," and its explanation depends on the fact that, owing to light moving progressively and not instantaneously, and the eye of the ob-

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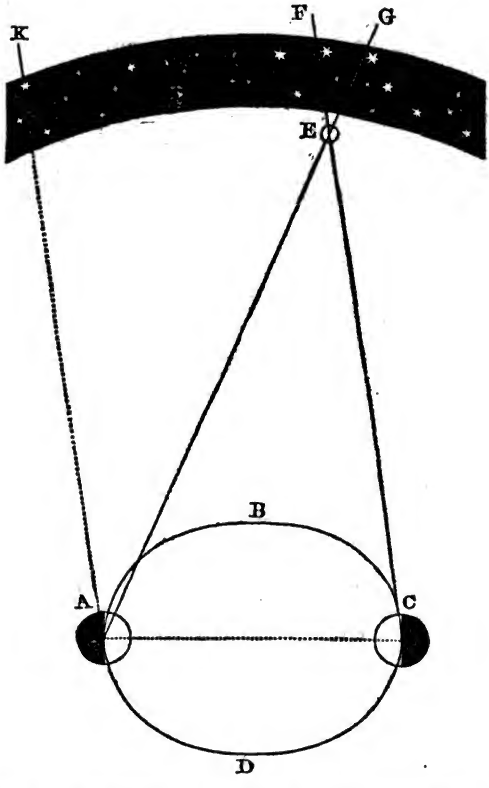
Why is the figure of a planetary body thus connected with its rotation on its axis? How was the aberration of the fixed stars first discovered? What is the direction of the apparent motion of a star compared with what it should be from parallax?

Fig. 370.



server accompanying the earth in her orbit, the position of the stars is not the same as what it would be were the earth at rest. The cause of this has been explained in Lecture XXXVI.

It is constantly observed of true physical theories that they afford explanations of facts, and, on the other hand, receive illustrations from facts with which, at first sight,

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How is this motion explained?

they did not seem to be connected. The aberration of the fixed stars proves two of the most prominent physical theories with which, at the first sight, it does not seem to be in the slightest degree allied—the progressive motion of light, and the earth's motion round the sun.

It is often a most important problem to determine the position of a given point on the earth's surface. Navigation essentially depends on determining with precision the place of a ship at sea. To effect this two problems have to be solved—to find the latitude and also the longitude.

The former of these is the more easily determined of the two. It may be done in several different ways; such as by the zenith distance of stars, meridian altitudes of the sun, or the east and west passage of a star through the prime vertical. The latitude of a place being the elevation of the pole above the horizon, among other methods it may, therefore, be ascertained by finding the greatest and least altitudes of a circumpolar star, half the sum of those altitudes being equal to the latitude. Of course, latitude is of two kinds—northern and southern. In any given instance, we indicate which by the letter N or S.

In like manner, there are several ways by which the longitude of a place may be determined. Longitude is estimated by the number of degrees upon the equator, intercepted between the meridian of the place of observation and the meridian of some other place, taken as a standard or starting-point, such as the meridian of Greenwich or Washington. Since a given point on the earth makes one complete revolution of three hundred and sixty degrees in twenty-four hours, it will describe in one hour fifteen degrees. In two places which are fifteen degrees of longitude apart, the sun comes on the meridian of the more westerly one hour later than on that of the other. To find the longitude, therefore, is to find the difference of the time of day between the place of observation and that taken as the standard. For this purpose chronometers are employed.

The eclipses of Jupiter's satellites and occultations of stars by the moon, are predicted in appropriate almanacs,

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How is the position of a place on the earth determined? How may the latitude be found? How is longitude estimated? How may it be found? What use is made of the eclipses of Jupiter's satellites and occultations?

with the exact moment of their occurrence at the standard meridian. It is, therefore, only necessary to mark the time at which one of these occurs at the place of observation, and the difference of the times gives the longitude.

LECTURE LXXII.

OF PERTURBATIONS.—*Action of Three Bodies.—Variation from an Elliptic Orbit.—Inequalities of the Moon.—Conjoint Action of the Sun and Earth upon the Moon.—Annual Equation.—Change in Position of the Nodes.—Precession of the Equinoxes.—Discovery of the Planet Neptune.*

ON the principles of mechanics it may be demonstrated that if a solitary planet revolve round a central sun, the path which it describes must be an ellipse, from which it would never deviate. But if a second planet or other attracting body be introduced, then it follows, as a direct consequence of the principle of universal gravitation, that disturbance will ensue, and the revolving bodies, instead of moving in exact ellipses, will follow new paths according as their relation of distance to each other changes.

These results, which we thus foresee theoretically, are verified in the heavens. The planetary bodies of our solar system do not, as we have heretofore supposed, pursue invariable elliptic paths round the sun, but each planet attracts all the rest in the same way and under the same laws that the sun attracts them all. His superior mass predominates, and gives its general character to the resulting movement, but the impression which each one makes upon its neighbor is plain enough to be traced.

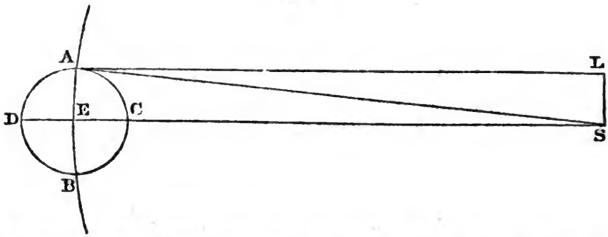
To these disturbances the general name of perturbations is given, and when they occur between planets and satellites the name of inequalities. They are secular and periodical. In every instance they compensate one another, so that after a certain period has elapsed, the dis-

What, on the principles of mechanics, must be the path of a single planet? If, instead of two, there be three bodies, what will be the result? How does this apply to the solar system? What is meant by perturbations and inequalities? Of what kinds are they?

turbances have neutralized themselves, and every thing is brought back to the original condition.

The inequalities of the moon and the earth furnish us with a clear illustration of these principles. In her monthly revolution round the earth, the moon alternately approaches to and recedes from the sun. Her distance from the earth being about 240,000 miles, her distance from the sun at conjunction and opposition differs by almost half a million of miles, and under the law of the inverse squares, his attractive force upon her correspondingly changes. When in conjunction—that is, between the earth and the sun, his attraction acting more powerfully on her—she approaches toward him, and her distance from the earth therefore increases: when in opposition, the earth being the nearer, is more powerfully attracted, and again the distance between the two is increased. Thus, let S, *Fig.* 371, be the sun, E the earth, and A D B C the orbit of the moon. If the moon be at her quad-

Fig. 371.



rature, A, the distances of the moon and earth from the sun are equal, and the attractive force may be represented by the lines A S, E S. Draw A L parallel and equal to E S, and complete the parallelogram E A L S. The force A S may be decomposed into two, A E directed toward the earth's center and A L. While A L acts parallel to E S, it does not produce any disturbance, but A E acting toward the earth's center, increases the weight or gravity of the moon, and makes her fall more toward the earth: and the same will take place in the other quadrature, B.

For these reasons we see that in the moon's conjunc-

Give an illustration of these principles in the case of the sun, earth, and moon.

tion and opposition her gravity toward the earth is diminished, but at the quadratures it is increased. So that if we were to conceive the sun absent, and the moon revolving round the earth in a circle, if the sun were then introduced his influence would make her describe an ellipse, the longest axis of which would be at the quadratures. It may seem somewhat paradoxical that the moon should come nearest the earth when her weight is least; but this is only an incidental thing: it arises from the circumstance that her approach is the result of the great curvature of her orbit at the quadratures, and arises from the velocity and direction she has acquired in conjunction or opposition.

Under these circumstances the velocity of her motion changes. The velocity diminishes from conjunction up to the first quadrature, then increases up to opposition. It diminishes again to the second quadrature, and increases to conjunction.

It further follows, from the same principles, that, as the earth revolves in her elliptic orbit round the sun, at one time approaching to him and at another receding, new variations will arise, because the relative distances of the earth, the moon, and the sun are changed, thus giving rise to another inequality, which is called the *annual equation*.

The foregoing explanation will set in its proper light the nature of perturbation, and show how it necessarily arises from the theory of gravitation. The subject in itself is exceedingly complicated in its applications, and far exceeds the limits which I can here give to it. Connected with the foregoing we may, however, trace a second instance. The moon's nodes, or the points where her orbit intersects the ecliptic, undergo an annual change of position of more than 19°, making a complete revolution in a little more than eighteen years and a half. This disturbance arises from the attraction of the sun; for as the moon's orbit is inclined at an angle of five degrees to the ecliptic, as she revolves round the earth and approaches

---

At what periods is the moon's gravity to the earth increased and at what diminished? What effect does the sun exert on the orbit of the moon? What changes take place in the moon's velocity? What is meant by the annual equation? What is the cause of the retrogradation of the moon's nodes?

the plane of the ecliptic, the sun's action brings her down more quickly, and makes her cross the ecliptic sooner than she would otherwise have done.

The last of these perturbations to which I shall now allude explains the cause of the *precession of the equinoxes.* At the time that names were given to the signs of the zodiac the vernal equinox coincided with the first point of Aries. It is now more than thirty degrees to the westward; for the sun crosses the equator each year at a point fifty seconds west of that in which he crossed it the preceding year; and thus the equinoxial points will make a complete revolution in 25,867 years, the seasons then having completely run through all the months of the year.

This phenomenon arises from the oblate figure of the earth, resulting from her rotation upon her axis, the sun's attraction being exerted upon the zone of matter which surrounds the earth like a protuberance at the equator, and tending to make it approach the plane of the ecliptic. The equinoction points—the points where the ecliptic and equator intersect—therefore recede, and the axis of rotation of the earth moves with a conical motion round the axis of the ecliptic. The pole of the earth's axis describes, therefore, a circular motion round the pole of the ecliptic, completing its revolution in 25,867 years. In successive ages the earth's pole points to different stars, which become pole-stars in succession.

These examples may afford a general idea of the nature of PERTURBATIONS, and show that, though they give rise to effects which might appear contradictory to the theory of universal gravitation, they are in reality, as has been already observed, the necessary consequences of it. The cases that we have been considering are very simple; but we can understand how difficult such problems become where more complicated systems are under investigation—as, for example, Jupiter with his four satellites, or Saturn with his ring and seven. Yet to so high a degree of perfection has modern astronomy advanced, that Herschel asserts "that there is not a perturbation, great

---

What is meant by the precession of equinoxes? In what time do the equinoxial points make one revolution? From what does this motion arise? In what direction does the earth's axis consequently move? Do any known perturbations affect the validity of Newton's theory?

or small which observation has ever detected which has not been traced up to its origin in the mutual gravitation of the parts of our system, and been minutely accounted for in numerical amount and value by strict calculation on Newton's principles!" And of late we have witnessed one of the most brilliant results of modern astronomy in the discovery of the planet Neptune. For it was seen that Uranus exhibited disturbances in his motions not accounted for by the action of any known body. These evidently pointed to the existence of some other mass beyond him, which, though unseen, was exerting its influence. The magnitude of this body and the position it should occupy were determined by the calculus; and, on examining the region of the heavens designated, the planet was found.

LECTURE LXXIII.

Of the Measurement of Time.—*Sidereal Day.—Solar Day.—Sidereal Year.—Equation of Time.—Mean and Apparent Time.—Incommensurability of the Day and Year.—The Julian Calendar.—The Gregorian Calendar.—Conclusion.*

If we examine, by proper instruments, the time which elapses between the successive passages of any star whatever over the meridian, we shall find that it is uniformly 23 hours, 56 minutes, 4 seconds. It is immaterial what star is watched; all give the same result. To this period the name of a *sidereal day* is given.

But if, with the same instruments, we examine the meridian passages of the sun we find that he does not come upon the meridian until 3 minutes and 56 seconds later each day, the clock measuring 24 hours between each passage. To this period the name of a *solar day* is given.

Now, the apparent revolution of the celestial bodies is due to the actual rotation of the earth on her axis. It would seem that the sun and the stars ought all to accomplish that apparent revolution in the same space of

---

What is meant by a sidereal day? What is its length? What by a solar day? What is its length? What do we infer as respects the apparent motion of the sun?

time. It is, therefore, obvious that the sun must move every 24 hours about one degree to the east: such a motion accounts for his coming later on the meridian; for one degree is passed over in about four minutes of time, which is very nearly the period of retardation we have observed. In 90 days the sun comes on the meridian six hours later than the star with which he was first compared. In about 180 days he is 12 hours later. In a little more than 365 both come on the meridian together again. But this apparent easterly motion of the sun is in reality the orbitual motion of the earth in the opposite direction, and the solar day differs from the sidereal by reason of the revolution of the earth round the sun. If that revolution did not take place, and the earth only turned on her axis, the solar and sidereal days would be exactly of the same length; but that revolution existing, to bring the sun upon the meridian, the earth must make a little more than one revolution each day, and, at the end of 365 days, must turn on her axis 366 times—that is to say, in a year there is one more sidereal than there are solar days. The actual length of the sidereal year is 366 days, 6 hours, 9 minutes, 12 seconds.

These considerations show how the measurement of time becomes complicated by the annual motion of the earth round the sun; and, as the axis of the earth is inclined to her orbit, and she moves with different degrees of velocity in different parts of her elliptic path, more swiftly as she approaches the sun and more slowly as she recedes, the length of the days will vary from time to time, when compared with a clock that goes truly, giving rise to a difference between the time indicated by the sun and a clock—a difference which is called the *equation of time*. *Mean time* is that indicated by the clock, and *apparent time* that indicated by the sun.

From the inclination of the earth's axis to the ecliptic it comes to pass that about the 20th of March, the 21st of June, the 23d of September, and the 21st of December the sun and the clock would agree; but between March and June the sun is faster than the clock; from then until September it is slower, and so on. The differ-

How does his meridian passage compare with that of any given star? What is the length of the sidereal day? To what is this difference due? What is equation of time? What is mean time? What is apparent time?

ent velocity with which the earth moves in her orbit complicates this, and from the two causes together the coincidence takes place on other days—on the 15th of April, the 15th of June, the 31st of August, and the 24th of December, while the greatest difference between the sun and clock, amounting to 16½ minutes, takes place on the 1st of November.

The principal natural division of time is into days and years—a division which is based upon civil wants, and which, therefore, from the earliest period was adopted. At a very remote time it was discovered that the year contained about 365 days; and this was probably the first exact division; but after a while it was discovered that the two periods are in reality incommensurable, and that there are more than 365 and less than 366 days in a year. The tropical year, as we have already stated, consists of 365 days, 5 hours, 48 minutes, 49 seconds.

The first great historic change in the calendar was made by Julius Cæsar, who, having learned in Egypt, that the year really consisted of 365 days and 6 hours nearly, endeavored to include these 6 hours by adding one day to each fourth year. So he instituted three years of 365 days, and a fourth of 366. The latter was called *Bissextile.* The twelve months consisted, some of thirty and some of thirty-one days, but February had only twenty-eight in common years, and to it twenty-nine were given in bissextile. This is the *Julian calendar.*

It is evident, however, that Julius Cæsar had thus overcompensated the year. It does not consist of 365 days and 6 hours, but wants 11 minutes and 11 seconds of it. For a short period this small quantity may be neglected, but in the course of centuries it becomes very appreciable. In the year 1582 it had amounted to more than ten days. At this time Pope Gregory XIII. published a bull requiring that ten days should be cut off from that year, and the fifth of October be reckoned as the fifteenth, and by a most ingenious and simple contrivance, provided against the future recurrence of the difficulty. The years are to be

---

On what days do the sun and the clock agree? When is there the greatest difference? What is the principal division of time? Are the day and the year commensurable? What is the length of the tropical year? What is the Julian calendar? In what was it defective? What was the excess of compensation?

enumerated by the vulgar chronology of the birth of Christ, and each year, the number of which is not divisible by 4, is to consist of 365 days; but every year which is divisible by 4 must have 366, except it be also divisible by 100. Every year which is divisible by 100, but not by 400, has 365, and every year divisible by 400 has 366.

The result of this is, that in 400 years three bissextiles are cut off. The year 1600 was bissextile; 1700, 1800, and 1900 are not; but the year 2000 will be, and so perfect is this contrivance that the derangement will be less than one day in the course of 3000 years. Even this might be avoided if the years divisible by 4000 should be made to consist of 365 days, and then, in the course of one hundred thousand years, the derangement of the calendar would not amount to a single day. This is the *Gregorian calendar*, or new style. It is received now in all Christian countries, save those in which the mode of faith is according to the Greek church—their years and festivals occur twelve days later than ours.

It is scarcely necessary to add the subsidiary division of time:—The week, consisting of seven days—a primeval division, which is to be traced in all countries, and which has survived all legislative enactments and changes of empires, because it is suitable to the wants, and commends itself, with its seventh day of rest, to the well-being of man; the month, which consists of four weeks; and the seasons, of which there are four in each year—spring, summer, autumn, and winter. The names of the seven days of the week are derived from those of the sun, moon, and planets—an observation which holds even for modern languages. These names were imposed by pious men at a very remote period; for they, having remarked the geometrical beauty of the revolutions of the stars, and the amazing punctuality with which they complete their periodic motions, were led to suppose that they were guided by, or rather were the residences of intellectual principles. They little foresaw how the great discovery of Newton—universal gravitation—would remove the hypothetical beings they thus worshipped, from the domains

---

By whom and when was this corrected? How did he adjust the calendar? To what degree of perfection does this division reach? What is New Style? In what countries is it not adopted? What other popular divisions of time have we? From what are the names of the days derived?

of the solar system, and replace them by one far-reaching mechanical principle—a principle so enduring, so unchangeable, that relying on it the astronomer is able to look equally into the past and the future, reproducing ancient events, or predicting those that are to take place in coming centuries; and this not in a doubtful or shadowy manner, but with all the precision of time, place, and circumstance. And this is the uniform course of human knowledge: things which are imputed by one generation to special and incessant interpositions of divine agents, are discovered by another to be the direct results of eternal and uniform laws; and the Universe, far from owing its permanence and regularity to the cares of a thousand gods and goddesses, contains within itself its own principles of conservation—all its perturbations run through their particular cycles, and then they compensate themselves, and every thing returns to its pristine condition. It contains no element of destruction, nor even of decay, and could, under the simple laws impressed upon it, continue its existence through all eternity, except its Almighty Maker—a monument of whose power and wisdom it is—should see fit to interfere.

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